AOTRAUMA

Thieme

Matthew Porteous | Susanne Bäuerle

Techniques and Principles for the Operating Room

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1190 illustrations/figures in total

Table of contents

Introduction

Textbooks of trauma surgery have traditionally been produced for surgeons. Yet operating room personnel (ORP) are as involved in the technical aspects of trauma surgery as the surgeons with whom they work. Indeed the surgeon is totally reliant on them before surgery to understand what will be required and have the right equipment when needed, and during the operation to understand what is happening and anticipate the surgeon's needs.

The *Techniques and Principles for the Operating Room* book is intended to bridge this gap. The first section, written by very experienced trauma ORP worldwide provides an overview of elements that make up an efficient trauma operating room. The second section, written by distinguished AO surgeons discusses the principles on which modern trauma management is based to give ORP an understanding of why certain fractures are managed in one way rather than another. This section is not intended to be comprehensive but to provide a concise outline of the theory of fracture management with suggestions in the further-reading part of available sources for those wishing to extend their understanding.

The final section describes individual common operations. These are laid out in a standard logical method and are intended primarily for the ORP about to undertake an unfamiliar procedure, although junior surgeons may also find them helpful. In each operation one method of fixation is described in detail; however, common alternatives are mentioned in the operative details or in the surgeon's key points at the end.

A book of this type cannot be fully comprehensive and cover every conceivable operation. We have tried to select operations that are either common or representative yet inevitably we will not have covered all eventualities.

We expect that this book will make interesting and informative reading and studying for those with an inquisitive mind wanting to know more about the rationale for using one technique as opposed to another. We trust that our book will also help and reassure any ORP with preparing and assisting at an unfamiliar procedure.

Contributors

Editors

Matthew Porteous, FRSC, FRCS(Orth)
West Suffolk Hospital
Hardwick Lane
Bury St Edmunds
Suffolk IP31 2LW, UK

Susanne Bäuerle, RN
ORP Manager
AO Trauma International
Clavadelerstrasse 8
7270 Davos, Switzerland

Authors

Theerachai Apivatthakakul, MD
Associate Professor
Department of Orthopaedics
Faculty of Medicine
Chiang Mai University
110 Intavaroroj Road
Chiang Mai 50200, Thailand

Michael R Baumgaertner, MD
Professor
Department of Orthopaedics & Rehabilitation
Yale University School of Medicine
PO Box 208071
New Haven, CN 06520-8071, USA

Shaul Beyth, MD, PhD
Orthopedic Surgery Department
Hadassah–Hebrew University Medical Center
PO Box 12000
Jerusalem 91120, Israel

Piet de Boer, MA, FRCS
Medical Education Consultants GmbH
Oberdorfstrasse 1
8305 Dietlikon, Switzerland

Christine Booth, SRN, MA (Medical Ethics and Law)
University Hospital of North Staffordshire
Royal Infirmary
Princes Road
Hartshill, Stoke-on-Trent
Staffordshire ST4 7LN, UK

Mariusz Bonczar, MD, PhD
Intermed Medical Center
UI Rydlowka 44
30-363 Krakow, Poland

Richard Buckley, MD, FRCS(C)
Department of Surgery
Division of Orthopaedics
University of Calgary
1403–29 Street NW
Calgary AB T2N 2T9, Canada

Doug Campbell, ChM, FRCS(Ed), FRCS(Orth), FFSEM(UK)
Consultant Hand and Wrist Surgeon
Leeds Teaching Hospitals NHS Trust
Leeds LS9 7TF, UK

Peter Campbell, MBBS, FRCS(ED)Orth
Consultant Orthopaedic&Trauma Surgeon
York District Hospital
Wiggington Road
York, YO3 7HE, UK

Fabio Castelli, MD
Dirigente Medico I Livello
Dipartimento Emergenza ed Accettazione
DEA Ospedale Niguarda–Milan
20122 Milan, Italy

Sari Cohen
AO ORP Course Manager
Geula 9 app, 11
Kfar-Sabba 44254, Israel

Klaus Dresing, MD
Clinic of Casualty Surgery, Trauma, Plastic and
Reconstructive Surgery
University Medicine Goettingen,
Georg-August-Universität
Robert-Koch-Str. 40
37075 Goettingen, Germany

Rossana Fornazzari, RN
Ambulatory Surgery
Hospital del Trabajador Santiago
Ramon Carnicer 201
Providencia
750-0000 Santiago, Chile

Peter V Giannoudis, MD, FRCS
Professor
Academic Department of
Trauma & Orthopaedic Surgery
Clarendon Wing, Floor A
Leeds General Infirmary University Hospital
University of Leeds
Leeds LS1 3EX, UK

AF Graeme Groom, MA, MB FRCS
Consultant Orthopaedic Surgeon
King's College Hospital
Denmark Hill
London SE5 9RS, UK

Roshdy Guirguis, BSc, MBBS, FRCR
Consultant Radiologist
Radiology Department
West Suffolk Hospital
Hardwick Lane
Bury St Edmunds
Suffolk IP33 2QZ, UK

David J Hak, MD, MBA
Associate Professor
Orthopaedic Surgery
Denver Health/University of Colorado
777 Bannock Street, MC 0188
Denver, CO 80204, USA

Ian Harris, MBBS, MMed(Clin Epid), PhD,
FRACS(Ortho)
Professor of Orthopaedic Surgery
University of New South Wales
Sydney NSW 2052, Australia

Jessica Hayes, BSc(Hons), PhD
Post-doctoral Research Associate
Implant Bioperformance Group
AO Research Institute Davos
Clavadelerstrasse 8
7270 Davos, Switzerland

James F Kellam, BSc, MD, FRCS(C), FACS,
FRCS(I)
Carolinas Medical Center
1000 Blythe Blvd
Charlotte, NC 28232, USA

Nicola Kildea, BA (Nursing), Grad Dipl
Nursing Perioperative
Royal Adelaide Hospital
North Terrace
Adelaide SA 5000, Australia

Mamoun Kremli, MBBS, FRCS
Department of Orthopedics 49
College of Medicine
King Saud University
PO Box 2925
Riyadh 11461, Saudi Arabia

Siew Hong Lau, RN, OTNC, CM, BA
Singapore General Hospital
Outram Road
Singapore

David Limb, BSc, FRCSEd(Orth)
Consultant Orthopaedic Surgeon
Leeds General Infirmary
Great George Street
Leeds, LS1 3EX, UK

Paulo R Barbosa Lourenço, MD
Chief Orthopaedic Trauma Service
Hospital Quinta D´or
Coordinator Orthopaedic Trauma Department
Hospital Ipanema
Rio de Janeiro, Brasil

Benjamine Ollivere, MBBS, MD, MA(Oxon)
MRCS
Specialist Registrar Trauma & Orthopaedics
Addenbrookes University Hospital
Hills Road
Cambridge CB2 0QQ, UK

Chris Moran, MD, FRCS
Professor of Orthopaedic Trauma Surgery
Nottingham University Hospital
Nottingham NG7 2UH, UK

Judy Orson, RN, BSc
The Princess Alexandra Hospital NHS Trust
Hamstel Road
Harlow
Essex CM20 1QX, UK

AD Patel, MBBS, FRCS
Department of Orthopaedics
Norfolk and Norwich Hospital
Colney Lane
Norwich, NR4 7UY, UK

Rodrigo Pesántez, MD
Professor
Chief of Orthopaedic Trauma
Fundación Santa Fé de Bogotá
Avenida 9 No. 117–20
Bogota, Colombia

Isabel van Rie Richards, BSc(Nursing)
Assistant Manager ORP
AOTrauma
Clavadelerstrasse 8
7270 Davos, Switzerland

Judith Roberson, RN
Orange Base Hospital
Sale Street
Orange NSW 2800, Australia

Nigel D Rossiter, MBBS FRCS(Ed)
FRCSEd(Tr&Orth)
Consultant Trauma & Orthopaedic Surgeon
Basingstoke & North Hampshire Hospital
Aldermaston Road
Basingstoke RG24 9NA, UK

Donna Russell-Larson, RN, CNOR
Ronald Reagan/UCLA Medical Center
757 Westwood Blvd
Suite 2400
Los Angeles, CA 90095, USA

Thomas P Rüedi, MD, FACS
em. Professor of Surgery
Founding and Honorary member of
AO Foundation
Schellenbergstrasse 20, Im Brisig
7304 Maienfeld, Switzerland

Myriam Sanchez, RN, MSc
Ambulatory Surgery
Hospital del Trabajador Santiago
Ramon Carnicer 201
Providencia
750-0000 Santiago, Chile

Daniël BF Saris, MD, PhD
Department of Orthopaedics
University Medical Center Utrecht
Heidelberglaan 100
3508 GA Utrecht, The Netherlands

Steven R Schelkun, MD
Chair, AO Trauma Education Commission
800 Pomona Avenue
Coronado, CA 92118-2340, USA

Rogier KJ Simmermacher, MD, PhD
Department of Surgery
University Medical Center Utrecht
Heidelberglaan 100
3584 CX Utrecht, The Netherlands

Contributors

Raymond Malcolm Smith, MBCHB, MD
Associate Professor in Orthopaedics
Harvard Medical School
Chief, Orthopaedic Trauma Service
Massachusetts General Hospital
55 Fruit Street, YAW 3600-C
Boston, MA 02114, USA

Edward Paul Szypryt, MBBS, FRCS
Consultant Trauma & Orthopaedic Surgeon
Nottingham University Hospitals
Queens Medical Centre
Nottingham NG7 2UH, UK

Wa'el S Taha, MD
Assistant Professor of Surgery
King Abdul Aziz Medical City
PO Box 22490
Riyadh 11426, Saudi Arabia

Bruce C Twaddle, BHB, MBChB, FRACS
Director of Orthopaedic Trauma
Auckland City Hospital
Park Road, Grafton
Private Bag 92-024
Auckland 1001, New Zealand

David Volgas, MD
Chief of Orthopaedic Trauma
University of Alabama at Birmingham
510 Twentieth Street South FOT No. 960
Birmingham, AL 35294, USA

Anna Wilkins, BA (Nursing)
Hawkes Bay Hospital
Omahu Road,
Hastings, New Zealand

Martin Wood, MA, FRCS, FRCS (Tr & Orth)
Department of Orthopaedic Surgery
West Suffolk Hospital
Bury St Edmunds
Suffolk IP31 2LW, UK

Merng Koon Wong, MD, MBBS, FRCS, FAMS
Director Orthopaedic Trauma Service
Director AO Center
Department of Orthopaedic Surgery
Singapore General Hospital
Outram Road
Singapore

Poh Yan Lim, BA, RN
Singapore General Hospital
Outram Road
Singapore

Acknowledgments

1 Operating room principles

1.1 Patient

Authors   Judy Orson, Donna Russell-Larson

1.1   Patient

1.1.1   Introduction

A patient coming to the operating room (OR) for surgery hands over the responsibility for his/her well-being and safety to the care of the perioperative team. Their role is to provide a safe environment through the application of their knowledge and skills; safeguarding each patient from harm and minimizing the risk of postoperative infection.

This chapter reminds OR personnel (ORP) of the principles of patient care during the preoperative phase of a patient's stay in the OR and offers guidelines for practice, transferable to the wide variety of settings in which ORP work.

1.1.2   Arrival in the OR

Arrangements for the admission of patients to the OR are varied. For example, some establishments have a designated preoperative area in which to receive patients or they may be taken directly to an anesthetic room or into the OR itself. No matter how this is organized, the environment where a patient first arrives should be quiet and calm where ORP can establish a rapport and complete the important checks that help ensure a patient's safety and well-being during his/her stay in the operating department.

The OR is an area of highly technical equipment and highly skilled personnel. Everyday sounds, smells, and machinery which are so familiar to ORP can appear intimidating and even frightening to a trauma patient arriving in the OR. The ORP who is first to greet the patient on arrival can help put him/her at ease with a friendly and professional approach. Greeting patients by name

and introducing themselves and any other person involved in their care is not only courteous but also reassuring and will help alleviate some of their anxiety. However, because ORP usually have only a limited amount of time in which to develop a rapport with a patient they must be perceptive enough to quickly ascertain each patient's psychological needs. ORP should remember to introduce themselves to any accompanying relatives/caregivers who also need consideration and reassurance.

Transfer to OR table

ORP should assess the patient's condition before transfer. If able the patient should be allowed to move onto the operating table (OT) with minimal assistance, but most trauma patients require help to transfer. No matter how this is organized ORP must make sure that the transfer is managed safely. The OT and patient trolley must be positioned properly with the brakes fully applied to both before the transfer begins. Adequate staff and moving aids, for example sliding devices, must be available to move the patient safely. Patients should be kept suitably covered to maintain their dignity and keep them warm. Before being moved the patient must be informed about the transfer, which should be carried out in a smooth and well-coordinated manner. Care must be taken of any intravenous or arterial lines, catheters, chest drains, and so on and the injured limb should be adequately supported.

Preoperative checklist

The most important duty of the perioperative team is to protect the patient from harm. Therefore, ORP must make certain that all required documents/orders/tests are present and complete and that a series of checks are performed in accordance with hospital policy before the patient is anesthetized.

Preoperative checklist

This should include but need not be limited to:

Correct patient	▪ Greet patient by name ▪ Confirm identity corresponds with the operating list, medical/nursing documents; and patient's identity bracelet which should show the patient's name, hospital number, and date of birth (it is recommended that patients undergoing general anesthesia wear two identity bracelets attached to different limbs)
Correct operative site marked	▪ Confirm site with patient, medical notes, and operating list ▪ Visually check for a mark at the correct site
Consent document completed	▪ Check patient understands and agrees to the surgical procedure ▪ Consent paperwork is complete and correct, signed, and dated (be aware of patient privacy and confidentiality)
Allergies	▪ Allergies should be noted on a separate patient identity bracelet
Premedication	▪ Check if a prescribed premedication has been given
Fasting time—nil per oral (NPO)	▪ Confirm time when patient last ate or drank
Dentures/dental work/prosthesis	Check if patient has: ▪ any dentures, loose teeth/caps or crowns ▪ hearing aids ▪ spectacles/contact lenses ▪ pacemaker or automated internal cardiac defibrillator ▪ prosthetic implants
Documentation	Check that all required documentation is with the patient including: ▪ medical and nursing notes with tissue viability assessment ▪ test results ▪ x-rays ▪ prescription chart showing current medication and medication taken on day of surgery
Jewelry and body piercing	▪ Other items must be covered and secured with tape, if not removed ▪ All tongue and lip jewelry must be removed before a general anesthetic

Authors   Judy Orson, Donna Russell-Larson

Patients should be treated as individuals. Although these preoperative checks are important in safeguarding every patient, additional information is sometimes relevant to the perioperative team. For example, a patient's injuries or mobility limitations may affect the manner in which the patient is moved and positioned, and the possibility of a patient being pregnant will have implications for radiological imaging and the possible effect of anesthesia.

Provision must be made for patients with particular needs, such as the disabled, those with sight or hearing impairments or special needs, and those who need an interpreter. Caregivers may need to accompany these patients right up to the induction of anesthesia to help with communication and transfer, and be available again for the postoperative care.

Pediatric patients need special consideration and should always have a parent or caregiver with them until induction of anesthesia or at an appropriate stage of the child's care. The child should be allowed to bring a personal item, such as a toy for comfort. ORP should greet both the parent and child in a friendly and professional manner and, as part of the preoperative check, ensure that the consent form has been completed correctly and where necessary signed by the parent/guardian in the appropriate place. Parents may become emotional and need sympathetic support and reassurance from ORP.

Preoperative verification for correct site surgery

Verification that the correct patient has arrived and is listed for the correct intended surgery or procedure on the correct operative site is an ongoing process that must be performed whenever the patient's care is transferred.

The risk of operating on the wrong site must be managed effectively. Procedures and protocols to promote correct site surgery should be available in all areas where surgery takes place.

The possibility of operating on the wrong site is an ever present danger. Preoperative marking of the operative site is important in promoting correct site surgery and ORP performing the preoperative checks must verify that the correct site is marked. Remember, anesthetized patients cannot speak for themselves and depend on the perioperative team to ensure that the right procedure is performed on the correct operative site.

The operative site should be marked with an indelible marker pen at or near the incision site with an arrow that will remain visible following the application of skin preparation, although plaster casts or other splints sometimes make this difficult. Marking of the operative site should take place preoperatively, ideally on the ward, and before the patient receives any premedication. Marking should be checked by the surgeon before the patient arrives in the OR.

At each transfer of the patient marking must be checked with the documentation to confirm the correct site.

Consent

The consent form documents the patients' agreement to the proposed surgery being performed and is confirmed with patients on their arrival to the OR. To give consent the patient should be given relevant information regarding the surgery and be able to understand that information and make an informed decision.

There may be instances when patients are unable to give consent themselves; for example, when a patient is unconscious or does not have the mental capacity to understand the information given. As a principle, no adult can consent for another adult and it is the responsibility of the surgeon who is proposing the surgery to assess the patient's capacity to give or withhold consent. Although the next of kin and family members should be consulted and involved in any decisions whenever possible, the final decision to

proceed with surgery rests with surgeons who should always act in what they believe is in the best interests of patients who do not possess the capacity to make that decision for themselves.

The consent process can be complex and must comply with legislation relevant to each country. For example, the age at which children can be considered competent to give consent for themselves can vary from country to country, so ORP must have the knowledge and awareness of legislation that governs patient consent within their country.

Emergency arrival in OR

Patients with polytrauma need urgent treatment and may arrive in the OR with little notice. Saving life and limb is the highest priority and in emergency situations it may not be possible to obtain all the usual information and perform the routine safety checks. For example, life-saving surgery should not be delayed because the limb is not marked. As much information as possible should be gathered to safeguard the patient from further harm, such as allergy details and any existing medical conditions that may affect immediate care. Every effort should be made to establish the identity of unconscious patients especially if there is more than one casualty involved. ORP should be prepared to manage anxious and distraught relatives who may also arrive in the operating department.

Infection control

ORP caring for patients arriving in the OR must be aware of infection control policies to minimize the risk of transmission of infection to staff and among patients. They should apply standard infection control precautions to all patients with whom they come into contact.

WHO Surgical Safety Checklist

Concern for patient safety is a global issue and ORP should be aware of the Surgical Safety Checklist developed by the World Health Organization (WHO) in its goal to improve the safety of surgical care worldwide. Three phases of an operation are identi-fied with a series of checks in each phase that have been proven to reduce the likelihood of serious, avoidable harm to the patient while at the same time promoting better communication and teamwork within the perioperative team. The team should confirm that the "sign in" (phase 1) checklist is completed before the induction of anesthesia.

Anesthesia

This section can only present an overview of challenges that confront anesthetists while caring for orthopaedic patients undergoing surgery. Patient acuity, airway management, length and type of surgery, and sometimes the surgeon's anesthetic preference determine the choice of anesthetic to be administered for a procedure or surgical intervention. Understanding anesthetic choices, airway management, and necessary circulatory support are primary concerns of the intraoperative orthopaedic team. Also, an awareness of the general anxiety of patients undergoing anesthesia and surgery should result in actions that lessen patients' apprehensions. For example, allowing patients to express their fears or concerns, remaining with the patient during the induction of anesthesia, and if possible assuring a quiet OR with lights dimmed are all valuable actions to minimize anxiety and fear during induction. ORP who are capable of evaluating and anticipating the needs of the anesthetist will facilitate optimal intraoperative care of the patient.

Patient acuity

There is considerable variation between the anesthetic needs of an otherwise healthy patient undergoing a minor procedure and a polytrauma patient with comorbidity health issues. The American Society of Anesthesiologists (ASA) standard monitoring for all patients includes pulse oximetry, noninvasive blood pressure cuff, electrocardiogram (EKG), and temperature control. When more extensive monitoring is indicated, it may include arterial and/or central venous pressures, pulmonary artery pressure, and transesophageal echocardiography. The need for more extensive monitoring devices depends on a history of serious cardiovascular or pulmonary disease, the severity of the patient's injuries, the

Authors   Judy Orson, Donna Russell-Larson

type and duration of the surgical procedure, and the patient's position. A preoperative discussion with the anesthetist and surgical team regarding these issues facilitate patient care.

Airway management

Proper assessment of a patient's airway and nil per oral (NPO) status before any surgical intervention is imperative to ensure patient safety. Does the patient present with a normal or difficult airway? When it is obvious that the patient has a difficult airway, such as with an unstable neck injury, or when cervical collar/halo traction is in place, planning for the additional equipment required for fiber optic intubation should be a part of preoperative room preparation. However, an unexpected difficult airway may present at any time and require rapid access to specialized intubation equipment. Even in otherwise uneventful tracheal intubations, the anesthetist may need the assistance of ORP to provide downward or lateral pressure on the larynx to facilitate intubation.

Nil per oral status must be ascertained to prevent the possibility of pulmonary aspiration of gastric contents. When a patient has a history of bowel obstruction, an esophageal or gastric hemorrhage, recent ingestion of a meal, a profound history of uncontrollable gastroesophageal reflux, or has an acute trauma, special techniques are needed to accomplish endotracheal intubation safely. These include establishment of a reliable intravenous cannula, application of all necessary monitors, and preoxygenation before the start of anesthesia. ORP may then be asked to apply cricoid pressure during the induction of anesthesia (Fig 1.1-1). The cricoid pressure should be applied as firmly as possible with two fingers, pressing directly posterior (toward the spine). This should be maintained until the anesthetist indicates that the pressure can be released.

Special tracheal tubes may be necessary for some types of orthopaedic surgery. For example, it is advisable to use a wire-reinforced tube when surgery is to be performed on a patient in the prone position or where the head is turned sharply to the side opposite the

a

b
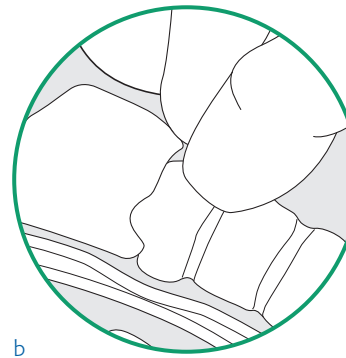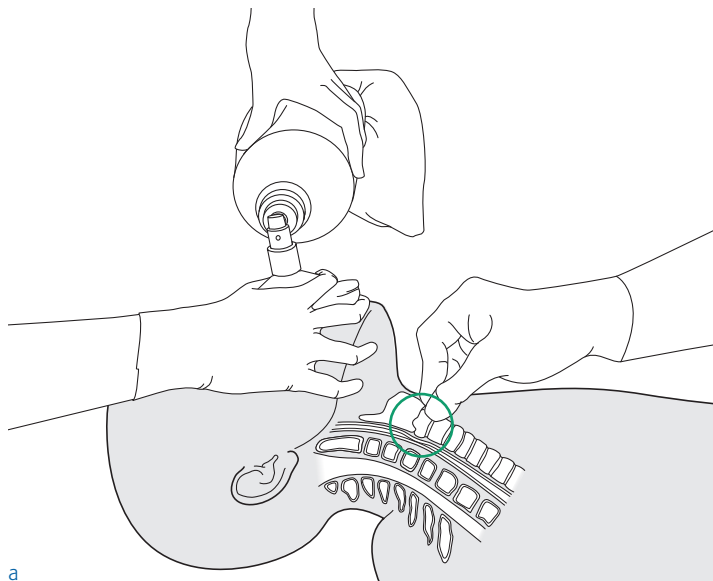
Fig 1.1-1a–b   Application of cricoid pressure. Note: cricoid pressure should be applied as firmly as possible with two fingers, pressing directly posterior (toward the spine).

operative site, such as anterior cervical laminectomies, upper shoulder, or clavicular surgery. This type of tube does not kink if bent at a right angle.

Anesthetic choices

There are four possible anesthetic choices for patients undergoing orthopaedic surgery:

Local anesthesia: the injection of local anesthetic by the surgeon at the site of surgery. For this type of anesthesia, ORP may be asked to prepare the local anesthetic to be used, apply monitoring devices as per institution policy, and perhaps provide oxygen via a plastic mask or nasal cannula. Local anesthesia may be combined with conscious sedation.

Conscious sedation (monitored anesthesia care): administration of sedative/hypnotic (midazolam, propofol, ketamine) and/or opiate (fentanyl, meperadine) drugs to allay anxiety and provide a measure of pain relief while the patient is undergoing a brief procedure, such as simple fracture reduction and casting, or relocation of a dislocated joint. If an incision rather than just manipulation is involved, such as a carpal tunnel release, the surgeon also has to administer a local anesthetic (lidocaine, bupivicaine, with or without epinephrine).

Regional anesthesia: administration of local anesthetics into the spinal canal or epidural space (spinal, epidural, caudal anesthesia) or directly injected onto a set of nerves, such as the brachial plexus (axillary, infraclavicular, supraclavicular, interscalene), or sciatic, femoral, popliteal, or more distal peripheral nerves (finger, wrist, ankle). Local anesthetic drugs, lidocaine, bupivacaine or ropivacaine, are used alone or more commonly in combination with epinephrine, opiates, and more recently clonidine (ß-adrenergic receptor antagonist) to prolong the duration of pain relief postoperatively.

A regional anesthetic may be administered in conjunction with a monitored anesthesia care or in addition to a general anesthetic. Regional anesthesia is advantageous for the elderly in that it may lessen the frequency, intensity, and duration of post-operative disorientation. Regional anesthetics in combination with a general anesthetic have the advantages that less general anesthetic is required to maintain the anesthetized state and postoperative pain management is more easily controlled. Patients with comorbidity, for example, cardiac/pulmonary conditions undergoing surgery, such as ORIF intertrochanteric fracture or total joint replacements, benefit from this combination of anesthetics. However, regional anesthetics are not without risk as inadvertent intravascular injection of a regional anesthetic may precipitate seizures, arrhythmias, or even death.

A Bier block is a form of regional anesthesia used for surgery on an extremity. A double tourniquet cuff is placed on the limb and intravenous access is acquired in the limb distally. The limb is exsanguinated using an Esmarch™ bandage and both cuffs are inflated to the desired pressure; then the distal cuff is deflated to allow tissue under the cuff to be anesthetized.

The Esmarch™ bandage is removed and a local anesthetic agent is injected into the limb. When the patient begins to experience pain from the proximal tourniquet cuff, the distal cuff, under which anesthesia has been established, is inflated and the upper cuff is deflated. This relieves pain from the upper tourniquet.

Should the proximal tourniquet inadvertently deflate shortly after the injection of the anesthetic agent, the patient may experience a sudden drop in blood pressure, lightheadedness, loss of consciousness, and even a seizure due to the release of a bolus of the local anesthetic into the central circulation. For this reason, if the operation is less than 1 hour, the tourniquet cuff should be intermittently deflated and reinflated to prevent too rapid release of the local anesthetic into the systemic circulation. If the operation is longer than 1 hour, the cuff can be safely deflated and not reinflated. ORP awareness of these possible complications is essential if a Bier block is the anesthetic of choice. ORP should also be aware that this technique is not suitable if the operation is likely to extend beyond 2 hours.

Authors   Judy Orson, Donna Russell-Larson

General anesthesia: administration of multiple drugs to provide amnesia, analgesia, neuromuscular blockade, and ablation of unwanted reflexes. This form of anesthesia may be administered via a laryngeal mask airway, or an endotracheal tube. ORP may be asked to assist with tracheal intubation as noted above. Occasionally, a regional anesthetic is converted to a general anesthetic and ORP may be requested to assist the anesthetist during this transition.

Tourniquet considerations

When a tourniquet is necessary for a surgical procedure, antibiotics should ideally be administered 10 minutes before inflation of the tourniquet cuff to assure a therapeutic blood level at the operative site. Muscle relaxation drugs should also be given before cuff inflation for optimal neuromuscular blockade. When the tourniquet is deflated there is a potential risk of the patient experiencing hypotension from sudden enlargement of the vascular bed as well as systemic acidosis due to the sudden release of anabolic waste products into the venous circulation. ORP should be aware of this and should be prepared to assist the anesthetist.

Potential complications

ORP should know the intraoperative complications specifically related to orthopaedic surgery that may affect anesthetic management. For example, reaming of the intramedullary canal may cause severe decreases in a patient's blood pressure and even fat embolization leading to difficulties in pulmonary ventilation, and rarely the development of adult respiratory distress syndrome. The anesthetist may request ORP to assist with rapid intravenous infusion of fluid or blood, or urgently procure specific drugs. In severe bleeding (eg, open fractures of large bones coupled with extensive soft-tissue degloving or severe pelvic fractures) additional staff may be required to help the anesthetist to support the patient's circulation. Knowing how to use a cell-salvaging machine is extremely helpful when anticipating the loss of a large volume of blood during a surgical procedure.

Anesthetic emergence

A patient awaking from a general anesthetic may develop laryngospasm after removal of the laryngeal mask airway or endotracheal tube and always requires an attentive anesthetic team. In orthopaedic cases, communication must be established between the surgeon and the anesthetist to ensure the patient remains anesthetized long enough to allow application of a cast or splint and/or the taking of postoperative x-rays when these are required.

Pediatric considerations

Children undergoing orthopaedic surgery present more challenges than most adults. Separation from parents, fear of the unknown, minimal understanding of the preoperative and operative environment, and perception that parents are fearful all contribute to making children anxious, cry frequently, and sometimes totally uncooperative. Reassurance by the ORP, allowing a parent to accompany the child to the OR, having him/her stay with the child until anesthetic induction is complete, and making a game of the application of essential monitors all serve to lessen most children's fear and anxiety.

If intravenous access is not possible, the anesthetist will resort to an inhalation induction using sevoflurane. ORP can be helpful in this setting by making certain that the OR is quiet and dimly lit, by holding the patient's hands or arms during the excitement phase, and assisting the anesthetist with establishing intravenous access once induction is complete. Airway management, induction and emergence, rapid desaturation, and heat loss all present situations in which ORP must be able to react quickly and effectively to assure patient safety.

Further considerations

A caudal anesthetic may be used for lower extremity procedures. Whether done before incision or postoperatively for additional pain control the anesthetist is likely to require support from ORP.

Communication between the anesthetist and ORP regarding patient acuity, planned airway management and anesthetic choice, tourniquet considerations, anticipated complications, anesthetic emergence, and pediatric considerations ensure the best possible care for orthopaedic patients.

1.1.3 Preparation for surgery

Surgery is invasive and has the potential to expose the patient to infection as the body's natural defense system, the skin, has been breached. The purpose of preparing the patient for surgery is to reduce the risk of postoperative wound infection.

A variety of microorganisms are normally found on the skin. Some are transient bacteria and easy to remove with soap and water while others are permanently on the skin and more difficult to eradicate.

The patient's own skin flora is the most common source of postoperative surgical site infections. It is therefore important that measures are taken to reduce the level of skin flora before any surgical intervention.

The skin around the incision site should be clean. As damaged or broken skin presents an ideal site for colonization by microorganisms, the condition and integrity of the skin of every patient must be assessed before surgery and the presence of cuts, abrasions, rashes, or other skin conditions around the operative site documented. For example, the skin under a cast or bandages may require washing with soap and water to remove dirt or debris before application of antiseptic skin preparation. Open traumatic wounds may be heavily contaminated and should always be irrigated and cleaned with normal saline or another appropriate solution applied with a sterile sponge or soft brush before antiseptic skin preparation.

Preoperative hair removal

Whenever possible it is preferable not to remove hair preoperatively as the process itself carries a risk of damage to the patient's skin, providing an opportunity for microorganisms to enter and colonize.

Hair removal is only necessary if the hair is thick or long and will get in the way of the incision or contaminate the wound.

If hair needs to be removed, shaving with a razor should be avoided as this method traumatizes the skin leaving microscopic cuts and abrasions through which bacteria can enter. Electric or battery-powered clippers with a disposable or reusable head suitable for disinfection are less traumatic and should be used if possible (Fig 1.1-2). Hair removal should take place as close to the time of surgery as is practical in an area away from the sterile field, preferably in a separate room, as loose hair can scatter and compromise sterility.

Fig 1.1-2 Hair removal with battery-powered clipper.

Authors   Judy Orson, Donna Russell-Larson

1.1.4   Positioning for surgery

For surgery the trauma patient must be placed in a position that provides optimal access for the surgeon, allows the anesthetist safe management of the airway, with access to vascular devices and monitoring equipment and takes into consideration the position of any other equipment that is needed, such as the image intensifier.

Most body systems, including the cardiovascular system, respiratory system, nerves, muscles, joints, and the skin can be adversely affected by the patient's position on the operating table (OT). Thus, moving and handling a trauma patient requires planning, good communication, and teamwork to protect an already injured patient from further harm.

Effective communication among the surgeon, anesthetist, and ORP caring for the trauma patient is essential so that the needs of individual patients can be anticipated during positioning. Before positioning of the patient takes place a risk assessment should be undertaken by all members of the multidisciplinary team who must be aware of any factors that need to be considered, including:

- The clinical details of the patient's injuries, length and nature of the surgery, type of anesthesia, position required, the need for any additional equipment.
- The age and physical condition of the patients including any preexisting conditions, any implants/prosthesis, or mobility limitation that may cause a restriction to movement.
- The proposed sequence of the surgical procedures intended for a polytrauma patient so that positioning for each procedure can be planned.

Adequate staff members trained to use correct manual-handling procedures must be available for moving and positioning the patient, since poor manual-handling technique can harm both patient and staff.

Any movement of an anesthetized patient must only be done with the approval of the anesthetist who has responsibility for the airway. A coordinated approach is required with one person, usually the anesthetist in charge and a pre-agreed count or command used to initiate the move. Equipment, such as urinary catheters and intravenous infusions, must be unhooked and transferred with the patient. The injured limb must be cared for and properly supported while the patient is moved and positioned; if there is any suspicion of spinal injury, the patient must be log rolled to maintain spinal stability. The operating surgeon should be actively involved as he/she is ultimately responsible for positioning the patient safely.

The safety and well-being of the patient is the most important factor to consider during positioning, and the role of the ORP includes:

- The preparation of the OT and accessories, such as traction attachments; making sure they are clean and set up correctly and that all necessary equipment is available in the OR before moving the patient.
- Protecting the patient from diathermy burns by checking that once positioned none of the patient's skin is in contact with any of the metal parts of the OT.
- Preventing hypothermia and preserving the patient's dignity by not overexposing the patient during positioning.
- Ensuring that the patient is in the correct position before the skin is prepared and draping begins.
- The maintenance of pressure area care.

A conscious patient changes position as a reaction to pain and discomfort but an anesthetized patient is unable to respond in this way and relies on the intraoperative team to prevent injury. ORP must therefore have an understanding of the physiological problems associated with positioning, which can include:

- Damage to the skin and soft tissues: pressure damage can be caused by direct pressure, shearing of skin during movement, and friction of the skin when rubbed over a rough stationary surface.
  - Anesthetized patients need to be moved and handled carefully; pressure points on heels, sacrum, scapula, and back of head should be protected by well-padded support surfaces and appropriate pressure-relieving devices.
- Ocular damage as a result of corneal drying, abrasion, or pressure on the eyes:
  - Eyes should be closed with eye pads and lubricated when necessary.
- Injury to joints and extremities: great care is needed during positioning of anesthetized patients to avoid any unnatural movements of the body that would not normally be tolerated by a patient who is awake.
  - Correct body alignment must be maintained and joints and extremities supported at all times to prevent hyperextension injuries to the joints.
  - Special care must be given to patients with existing joint arthroplasties during positioning to avoid dislocation.
- Peripheral nerve damage: this may be caused as a result of direct trauma, compression, and stretching, and by pressure from tourniquets and blood pressure monitoring cuffs.
  - Padded supports to the upper and lower limbs should be used to minimize compression.

- Affecting the circulatory system: general and regional anesthesia causes a loss of vasomotor tone in the blood vessels, which, combined with the diminished muscle tone of a motionless patient on the OT, leads to pooling of blood and the increased risk of thromboembolism, ischemia, and in rare cases, compartment syndrome.
  - Compression stockings or intermittent pneumatic compression devices can be used prophylactically to aid venous return.

It is important that ORP put their understanding of these problems into practice when moving and positioning patients in the OR, and in addition, recognize the specific considerations needed to protect the patient from injury when being placed in different positions required for trauma surgery.

Documentation

Documentation provides a reliable record of care given to the patient and should include:
- Skin condition before and after procedure
- Position of the patient for surgery, including the type of support and pressure-relieving devices used
- Names and designation of staff involved in positioning the patient

Authors   Judy Orson, Donna Russell-Larson

| Position	Positioning points	Special considerations

Supine	■ Body in alignment
	■ Legs parallel and uncrossed
	■ Secure arms
	  – By patient's side
	  – Flexed across chest
	  – Abducted on arm boards
	    (Fig 1.1-3)
		■ Protect sacrum, thoracic vertebrae, scapula, back of head
		■ Pads under heels
		■ Arms must never be abducted above 90° as this could cause a brachial plexus injury

Traction table	■ Counter traction supplied by a well-padded perineal post ■ Uninjured leg supported on leg holder ■ Arm on operative side held in sling (Fig 1.1-4)	■ Post should rest against pubic rami of operative side ■ Avoid pressure on external genitalia and prudendal nerve
Lateral	■ Maintain spinal alignment during turning ■ Stabilize pelvis, shoulders, and spine to prevent patient rolling ■ Protect arms and legs from pressure and nerve damage	■ Padded supports or a specialized mattress that becomes rigid once air is removed, prevent patient rolling ■ Axillary pad protects lower shoulder from weight of the chest ■ Upper arm supported in a padded gutter ■ Soft padding between legs ■ Pad pressure points—lower hip, shoulder, knee, and ankle
Prone	■ Maintain cervical and spinal alignment during turning–anesthetist in control of head ■ Adequate staff available for moving and positioning the patient to support the body, buttocks, arms, and legs ■ Use padded headrest to avoid pressure on eyes ■ Abdomen needs to hang free to aid respiratory function	■ Check tracheal tube after turning ■ Arms moved simultaneously and symmetrically. If flexed at elbow and positioned alongside the head, arms not abducted above 90° ■ Protect eyes with pads ■ Use specialty mattress with hole in center for abdomen or pillows under pelvis and chest to prevent abdominal contents pushing the diaphragm upward ■ Pad pressure points—forehead/face, iliac spines, knees, and feet
Beach chair	■ Half-sitting position of patient ■ Maintain neutral cervical alignment ■ Position and secure head in headrest ■ Free position of shoulder and arm to be operated on ■ Position and protect opposite arm ■ Support buttock, back, and pelvis ■ Knees flexed and supported ■ Protect heels to avoid pressure	■ Protect head, cervical spine, and tracheal tube ■ Avoid neck extension ■ Pad pressure points—head, arms, buttock, knees, and heels ■ Flex knees slightly to keep tension off sciatic nerve
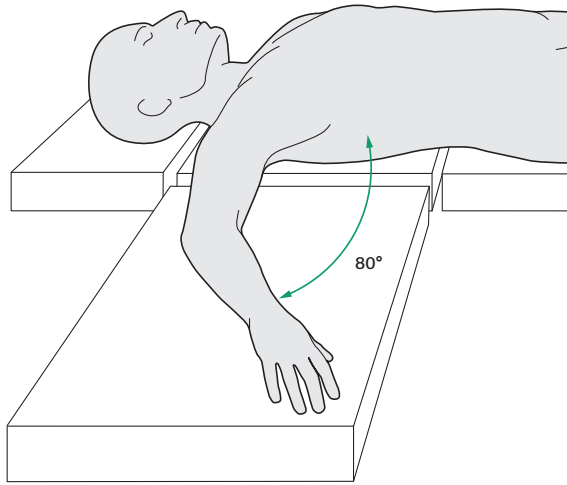
Fig 1.1-3   Arm positioned on an arm board with the shoulder abducted less than 90°.
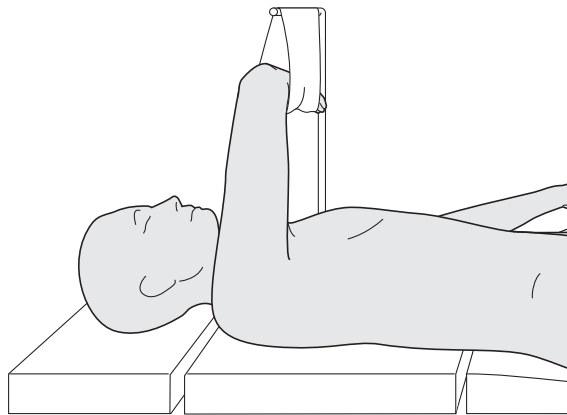

Fig 1.1-4   Arm positioned on the operative side in a sling.

Authors   Judy Orson, Donna Russell-Larson

1.1.5   Disinfecting and draping

Antiseptic skin preparation

Antiseptics that are used to prepare the skin immediately before surgery act against the resident and transient microorganisms found on the skin. They work quickly to reduce microbial levels and inhibit regrowth for a period to lower the risk of wound contamination by the patient's own skin flora.

The choice of antiseptic solution should not just be influenced by surgeon preference but should also be guided by the patient's skin condition, any known hypersensitivities to the solution, and the area to be prepared. For example, alcohol-based solutions should be avoided for use on mucous membranes or open wounds.

Antiseptic solutions can be supplied in single application, ready-to-use small containers, or multiuse bottles; although the latter can theoretically become contaminated each time the lid is removed and replaced. If multiuse containers are used, any solution remaining in them must be used or discarded before the expiry date and the bottles never refilled from another container.

The use of alcohol-based antiseptics, for example, providine iodine or chlorhexadine alcoholic solutions, carries some risks that ORP should be aware of:
- Alcohol-based preparations are flammable and the vapor has the potential to ignite in the presence of an ignition source, for example, sparks from an electrosurgical unit.
- Chemical burns can occur if the solution is allowed to pool beneath the patient, under a pneumatic tourniquet cuff, or electrosurgical unit dispersive pad.

Therefore, be cautious when applying alcohol-based antiseptics; allow time for the solution to dry before positioning drapes to avoid the build-up of fumes underneath them. Antiseptic solutions are also most effective when allowed to dry on the skin before draping. Be careful to avoid an accumulation of solution under the patient during skin preparation; absorbent material can be placed around the preparation area to soak up excess solution and then be removed before draping. A waterproof barrier, such as a plastic sheet placed around the limb under tourniquet padding, or sealing off the tourniquet from the operation site before skin preparation, prevents solution pooling beneath it.

Before antiseptic skin preparation begins the perioperative team should be satisfied that the patient has been positioned correctly and safely, the supports and pressure-relieving devices are in place and, if appropriate, the tourniquet has been inflated on the limb. The person preparing the surgical site should understand the principles of antiseptic skin preparation and have the training and skills to perform the procedure. Starting at the incision site, using sterile materials and a no-touch technique to avoid contamination of sterile gloves, the solution should be worked outward toward the periphery; the process repeated at least twice using a fresh sponge/swab each time. However, any areas considered to be contaminated, such as the pubis, axilla, or open wounds should be prepared last. Be aware that the prepared area should be sufficient to allow for enlargement of the incision, the inclusion of drain sites, and accommodate any accidental movement of the drapes. If bone graft is to be harvested the donor site should be prepared at the same time.

Details of skin preparation should be documented in the patient record as this provides an accurate account of the individual care given to each patient. As a minimum this should include:
- The preoperative condition of the patient's skin
- If relevant, the area where hair has been removed and the method of its removal
- Type of skin preparation used
- Name of the person(s) involved in skin preparation

Surgical drapes

Placed around the incision site, sterile drapes provide a barrier to protect the exposed tissues from contamination by microorganisms from nonsterile areas and any nonsterile equipment brought close to the sterile field. Drapes also have an important role in protecting the surgical team from contamination with body fluids from patients.

Drapes can be categorized into two types:
- Reusable: made either from tightly woven textiles such as the traditional cotton or linen drape chemically treated to provide a barrier against strike-through of microorganisms and fluids, or the newer microfiber textiles
- Disposable: single-use, nonwoven material

ORP will probably find the choice of drape type limited to local policy and availability but should understand how the performance of the drape affects its ability to prevent postoperative infection. Sterile drapes should:
- Act as a fluid-resistant barrier and be effective against strike-through contamination even when wet
- Be resistant to microbial penetration whether wet or dry
- Be as lint free as possible
- Be nontoxic
- Be strong enough to resist tearing whether wet or dry
- Be simple to use
- Be able to conform to the patient and equipment
- Be fire resistant and antistatic

In the surgical situation, although traditional woven fabrics have the strength and the ability to drape well, they have been found to be less resistant to the transfer of microorganisms to the incision site than disposable single-use materials that are most commonly used today. With repeated use and processing through the decontamination cycle, woven fabric drapes can become porous and lose their barrier effect. However, the new generation of textiles developed for use in reusable drapes, such as single-layer microfilament yarns, shows an improved performance and offers better protection against transfer of microorganisms than the traditional woven drape.

Draping the patient

Sterile drapes are applied once the skin has been prepared with antiseptic solution. Draping should be carried out by members of the surgical team who understand the principles of asepsis and have been trained and are competent in the technique:
- The patient's skin should be dry before drapes are applied
- Drapes should be handled as little as possible and held high over the patient to avoid contamination from nonsterile areas
- Sterile gloves are protected from contamination by cuffing the draping material over the hands
- Drapes should be placed at the incision site first and then carefully opened out to the periphery

Drapes should be fixed securely and once positioned should not be moved during surgery until dressings have been applied at the end of the operation

Sterile drapes are available in a variety of shapes and sizes that provide the protection necessary for most types of surgery. Disposable single-use drapes also have a range of special drapes designed to meet specific draping requirements, for example, the plastic isolation sheet used to drape the patient on the traction table and at the same time, isolate the C-arm of the image intensifier.

However, trauma surgery can produce some draping challenges that require preoperative planning to make sure a patient is draped effectively and safely (Fig 1.1-5); for example, the complexities associated with draping a polytrauma patient who may undergo multiple procedures simultaneously.

Authors   Judy Orson, Donna Russell-Larson

Final preoperative verification of correct site surgery

As part of the ongoing process of verification a final check to confirm the patient's identity, correct marking of the operative site, and correct procedure to be performed is advisable immediately before the beginning of a surgery or procedure.

Fig 1.1-5   Draping challenge of a polytrauma patient for follow-up surgery.

"Time out" (phase 2) of the WHO Surgical Safety Checklist should be done before any skin incision with involvement of the whole perioperative team who will participate in the intended surgical procedure. ORP must be aware of the protocol for addressing any discrepancies found during this check as the surgery must not be performed until any uncertainty has been resolved.

Conclusion

The goal of the perioperative team is to make sure patients are protected from harm and to minimize the risk of postoperative infection. As vital members of the team, ORP can safeguard patients when they are unable to act for themselves by providing skilled and knowledgeable care that meets each patient's individual needs and ensure a safe and successful stay for every patient in the OR.

1.1.6   Further reading

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Acknowledgment

1.2 Personnel

Authors   Rossana Fornazzari, Myriam Sanchez

1.2   Personnel

1.2.1   Introduction

"The most important resource for a company is the people who work there."

This quote is particularly applicable to the operating room (OR) where the success of surgery depends on the synchronization of three factors:

- Patient
- Personnel
- Environment

Operating room personnel (ORP) as the main pillar of this process must have a positive and responsible attitude, as well as develop technical competence through systematic training.

This chapter introduces ORP to the skills they need to develop to become key team members and provide a safe, high-quality, and efficient environment in which to perform trauma surgery.

1.2.2   Communication

Communication is the most important of all the skills required of the ORP. The medical world generates a vast amount of information concerning both the patient and the operation itself, much of which is technical. This aspect, coupled with the fact that surgery has traditionally had a hierarchical structure which has not always encouraged objective questioning, can be one of the greatest risks to the patient.

Despite existing security and safety measures to protect the patient from mistakes, investigations into surgical errors show that they are mainly due to a communication failure among team members.

Security elements

This relates to official patient safety routines and checks inside the OR to ensure that the correct patient is receiving correct site surgery. Just carrying out and recording these checks is not sufficient. The key is education of ORP as to how and why these checks are important. ORP must be aware of their role and responsibilities and how to implement them accurately.

Technical structure

To back-up patient safety and security there must be written protocols and checklists to ensure that nothing is omitted. These documents can be used as evidence when a root cause analysis is necessary after an error or near miss. They can also be subjected to audit and inspection to establish compliance rates.

Surgeons differ, and to ensure the smooth running of an operation ORP need to know the surgeons' preferences; for example, the types of implants likely to be used, special instruments required, and the suture material preferred.

There must also be methods to check OR schedules and ensure specialist equipment is available, particularly if there is only one set of a certain type of equipment. ORP must also check that equipment on loan has been ordered if it is likely to be required. The earlier potential problems are identified, the less likely that this will lead to disruption of a procedure (Fig 1.2-1).

Fig 1.2-1   ORP checking loaned equipment to ensure it is complete.

Oral communication

Oral communication is the major single factor in reducing risk in the OR and leads to greater job satisfaction for all. A content OR team is one in which the staff talk with each other, and if everyone feels comfortable communicating then mistakes are far less likely to occur. The reverse is true if junior staff feel unable to communicate any concerns they may have.

Good oral communication does not need financial investment but requires an investment in time and effort by all. Junior staff members tend to take their lead from their seniors. The more senior the staff members are, the more effort they must make to set a good example and they must be conscious that others may regard them as role models. This applies as much to the surgeon as to senior OR staff.

Face-to-face contact is particularly important for:
- Teaching staff, both in the appropriate protocols and paper-work, and how to handle and maintain equipment devices or material acquired by the OR.
- Correction of an impending mistake by a staff member. Timely intervention to prevent harm to the patient while maximizing the learning experience for the individual and the team is an important skill for senior staff to develop.
- Communicating with the surgeon to ensure the ORP know exactly what is required for any operation, and if it is not routine, how it is likely to be carried out. The more the team knows in advance the more they can anticipate and plan. Understanding just what has been done and why, is also a useful educational experience.
- Developing relationships among ORP, while maintaining the hierarchical structure in as relaxed a manner as possible.

Authors   Rossana Fornazzari, Myriam Sanchez

Formal communication and feedback

Formal monitoring of measures of quality assurance is an increasingly important part of the feedback received by the OR team. These give some measurable indicator of performance, patient safety, and increasingly value for money, which can be audited. Examples include surgical site infection (SSI) rates, fulfillment of the surgical schedule, intraoperative risk incidents, and cancelled operations.

OR staff may also become involved with audits that have a wider scope, such as joint registries or even taking part in research projects.

These are all useful tools to identify areas of concern and take corrective action before they become a significant problem and the patient's safety is compromised. Asking staff to collect additional data may seem like unnecessary extra work but these measures are only as accurate as the data recorded. Involving staff creates a feeling of shared ownership when problems are identified, giving everyone additional satisfaction when the results are positive.

1.2.3   Behavior and discipline

The first priority of the ORP is the well-being and safety of the patient and every team member has a responsibility to report anything that might jeopardize this, such as a lapse in aseptic technique or a missed safety check.

The roles and responsibilities of each team member, and how any breaches of standard procedures are handled, should be clearly written in the form of "operating room regulations" or in the "hospital procedure manual." The nature of these regulations varies among hospitals, and depends on such factors as the personnel mix, size, and case mix of a department.

The OR can be an extremely stressful place to work. Individual and team responsibilities are demanding and it is important that the workload does not surpass the team capacity, so that everyone feels able to work efficiently and safely and no one is tempted to cut corners.

The importance of each ORP recognizing that they have an overriding ethical duty to ensure patients' safety under all circumstances is a key educational consideration. Self-discipline and the development of a surgical consciousness in adherence to aseptic principles and sterile technique must not only be taught from the outset but also be regularly reinforced both by formal teaching sessions, but more important by senior team members setting a good example. Good leadership is partly about identifying individuals whose apathy might pose a risk to patient and team integrity, and educating them before it becomes an issue.

Admitting mistakes is something most people find difficult, but in surgery mistakes can and do lead to patients being harmed. It is important therefore to create an environment in the OR in which any error, for example, an incorrect swab count or missing instrument is owned up to immediately, and such behavior is recognized by all, particularly by the surgeon, as being ethically and morally correct.

It has been suggested that one way of reducing mistakes in the OR is to train staff to be multiskilled and take on any role from anesthetic assistant to scrub ORP. This promotes technical competencies, and ensures every team member knows each role carried out by the other. This may increase flexibility and job satisfaction; however, this can be at the expense of reducing individual expertise in any one area of the OR.

Complex technology

The current pace of technological advancement presents a series of challenges in the OR: how to introduce new technology, train staff to use it appropriately, and to keep up with the maintenance while maximizing its availability for surgical use, and for more delicate instruments how to minimize accidental damage to expensive equipment.

The introduction of computer networks can also cause problems. Software often fails to function as intended and is frequently complicated and not particularly user friendly. Some hospitals gather enough data to produce performance indicators; this is undoubtedly one of the ways that quality control will be monitored in the future. This means that all ORP will have to learn how to manage the computing systems in their hospital, and senior managers will need to be able to interpret and assess the information such systems generate.

Each additional layer of complexity in the OR makes the task of organization and education more difficult and increases the risk of staff spending too much time focused on the technology at the expense of their basic surgical disciplines, which must be regularly reinforced by good team practice and management.

Legal responsibility

OR staff work in an increasingly litigious society, and there is a growing threat of patients and staff members taking legal action against the hospital. The monetary and personal costs involved mean that managers are keen for staff to keep up-to-date with practice and responsibilities so as to reduce this risk.

New management models

Nowadays service quality is imperative. Public health care users are demanding improved standards; while in the private sector users expect their money to provide an even better and more personalized level of service.

The pace of change is now so rapid that it is no longer enough to only train personnel in specific tasks and duties. They must be given the tools required to train, develop, and adapt themselves to the fast-pace working environment in which they find themselves and to deal with the conflicts and interpersonal problems that such change brings in its wake.

A main feature in this type of training is the ability to prioritize. It is all too easy to lose sight of one's goals when under pressure from several directions at once, and the ability to handle multiple tasks while keeping patients' safety in mind and recognizing which tasks have priority can be greatly enhanced by appropriate training.

Outside influences

Personnel management does not stop with the immediate ORP. Managing an OR relies on others who are not familiar with this OR environment, for example, maintenance teams and visitors. These non-team members have to be instructed in basic dos and don'ts of working in an OR. Other professionals, such as time and motion specialists, psychologists, and sociologists may be invited to look at working practices to see how both the efficiency and the patient comfort and well-being can be improved. All these "outsiders" have a valuable contribution to make to the development of a well-ordered OR and must be welcomed and accommodated. This can sometimes be challenging particularly when their activities are regarded by some staff as being a threat to established working practices. Instead they should be seen as an opportunity to help staff adapt to the increasingly complex and changing environment of the OR where over the years, surgery and anesthesia have become more complex and paperwork more onerous.

Authors   Rossana Fornazzari, Myriam Sanchez

The OR is only one part of the complex system that makes up a hospital, and there is inevitably much interdependence among hospital departments. Pulling all these threads together and forging relationships with other departments without losing sight of the primary function of the OR—performing safe, high-quality surgery—is perhaps the greatest management challenge.

1.2.4   Universal precautions

The protocols required to protect health care personnel from exposure to biological products are called "universal precautions with blood and other body fluids." These protocols (techniques and procedures) are designed to protect health care personnel taking part in activities when there is direct contact with patients' blood or body fluids.

Universal precautions refer to the use of mechanical barriers (gloves, eye protection, protective clothing, and so on) when manipulating blood and certain body fluids, when using sharp instruments, handling biological material waste, and decontaminating soiled instruments.

Gloves
Gloves provide a barrier and are used to prevent contact of the hands and forearms with blood, secretions, and mucous membrane during a procedure or when handling surgical instruments.

They are used in surgical operations and other invasive procedures.

Surgical gloves are sterilized with gamma radiation and sometimes with ethylene oxide. They come packaged in individual double sachets. They are single-use only and therefore should not be reused.

Using sterile gloves does not replace hand washing and while affording protection to both user and patient, gloves will not resist a needle or sharp instrument penetration.

Double gloving is recommended when patients are known infectious risks to ORP; as well as in surgical procedures of long duration and those in which hard tissues, such as bone are handled, or if there is significant bleeding. This reduces the risk of penetration and gives additional protection against contamination. Some orthopaedic surgeons use cotton or Kevlar over gloves for further protection when handling bone. The protective effect of latex diminishes with time, so in longer procedures the regular changing of gloves is recommended.

Gloves of the correct size are recommended, especially for surgical procedures; ill-fitting gloves reduce tactile feedback to the user and can produce numbness in the fingers during prolonged use.

Most surgical gloves are made of latex. Latex-free gloves must be used if there is any suggestion that the patient or staff member is allergic to latex.

Sterile gloving
Perform surgical hand washing and select gloves of the correct size.

The closed-gloving principle is the technique of choice when initially donning sterile gown and gloves:

- Open the inner package, and identify the right and left glove in front of you.
- Through the gown, grasp the cuff of the left glove with the right hand and remove it from the pack (Fig 1.2-2a).
- Place the glove on the left wrist (Fig 1.2-2b).
- While still gripping the cuff of the glove, make a fist and pull the cuff over the hand, aiming to cover the knuckles and the thumb joint before straightening the finger on the left hand (Fig 1.2-2c–d).
- Maneuver the fingers to ensure a good fit (Fig 1.2-2e–f).

- The gloved left hand now picks up the right glove (Fig 1.2-3a).
- As before place the glove over the wrist, make a fist and pull the glove over the gown and maneuver to achieve a good fit (Fig 1.2-3b).
- Both gloves can now be adjusted without fear of contamination (Fig 1.2-3c).

When removing gloves it is good practice to ensure that the outer contaminated surface does not touch the bare unprotected hand. Always wash hands or apply alcohol after removal of gloves. This protects the skin of the hands. Be aware that often there are unnoticed perforations in the gloves.

Fig 1.2-2a–f   Closed-gloving technique for the left hand.

Authors   Rossana Fornazzari, Myriam Sanchez

Surgical gowns

Surgical gowns establish a mechanical barrier between the user and the patient, and thus maintain the sterile field for the patient and protect the user. Use of disposable and waterproof gowns is recommended for surgical operations as they are impermeable and less prone to leakage under extreme conditions. If these are not available, use gowns made of specialized waterproof cloth which tolerates repeated washing and sterilization.

The recommended model opens at the back; it should cover the back totally with contact zipper or with clasps at the neck and internal and external ties at the waist. The sizes should fit average to tall.

Fig 1.2-3a–c   Closed-gloving technique for the right hand.

Donning a sterile gown

The team member performs a surgical hand scrub:

- The gown is lifted upward and away from the table. The gown is grasped firmly at the neckline and allowed to unfold completely with the inner side facing the wearer.
- Slip both hands into the open armholes keeping the hands at shoulder level and away from the body. Push both hands and forearms into the sleeves of the gown, advancing the hands only to the proximal edge of the cuff in order to use the closed-gloving technique (Fig 1.2-4).
- The ungloved hand should never touch the front of the gown.
- The circulating nurse should secure the neck and waist ties, touching only the inner aspect of the gown while doing so.
- Following the donning of sterile gloves, the wrap-around gown can be closed and tied.

Masks

The mask is a filter which forms a protective barrier between user and patient and prevents transmission of microorganisms. They are disposable and come in different models; no substantial differences in efficiency have been found among the different types of material used. They must cover both nose and mouth. Even when wearing a mask the risk of contamination for the patient is increased by coughing and talking which should be kept to a minimum. Some mask models come with an attached eye-protection device to protect the user against splashes of body fluids (Fig 1.2-5).

Protective glasses

These are solely designed to protect the user against conjunctival contamination and subsequent infection by infected body fluids. This is an uncommon but recognized risk. They should be used
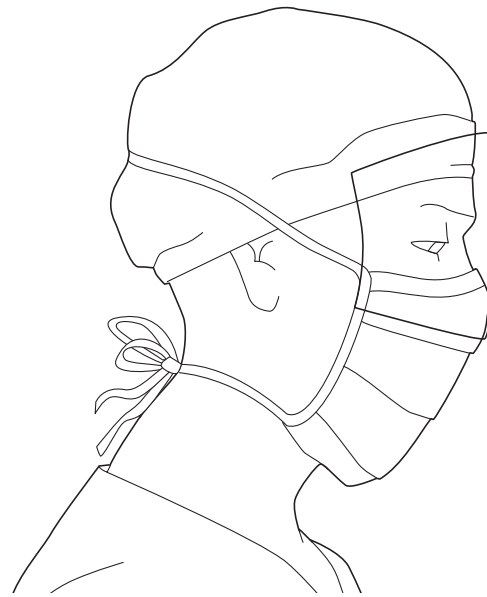

Fig 1.2-4   Hands are hidden in sleeves of gown.

Fig 1.2-5   Mask with eye protection.

Authors   Rossana Fornazzari, Myriam Sanchez

when operating on high-risk patients and in any operations where splashes are likely. It is important that any eye-protection device is comfortable and secure so it does not fall into the patient during surgery.

Personnel protection

Practicing universal precautions reduces the risk of transmission of infectious pathogens to patients and health care workers whether the patient is regarded as high risk or not. Universal precautions apply to every patient, every time.

These precautions must be practiced when handling potentially infected material, including body fluids:

- Highest risk: blood; fluids containing visible blood; wound drainage or exudates
- Others: semen; vaginal secretions; tissues; sputum; feces; fluids of cerebrospinal, symposia, pleural, peritoneal, amniotic

Universal precautions do not apply to the following materials unless blood is present: tears, nasal secretions, saliva, sweat, urine, or vomit.

Sharps management

During a surgical procedure the following precautions should be taken with all sharp instruments:

- Do not bend or recap needles.
- Do not touch sharp instruments, such as needles or scalpel blades, with the hands if they have been in contact with blood, or other body fluids.
- Open medicine ampoules using an ampoule opener or gauze swab.

Small sharp instruments, such as scalpel blades, needles, and others, must be left on the sterile instrument table in a "neutral zone" which has been previously agreed upon by the medical team. The surgeon will pick up sharp items placed there by the ORP to avoid risks of injury associated with passing such items hand to hand. Only one sharp instrument should be in the neutral zone at any

time, and the items are placed there to make it easy for the surgeon to pick them up with the dominant hand. As an alternative, ORP can pass the surgeon such items on a small tray.

All sharp items must be disposed of in special, puncture-resistant, leak-proof containers which are either red or labeled bio-hazard. When ¾ full they should be sealed and replaced.

Checklist for safe assisting during sterile procedures:

- Avoid handling needles manually.
- Never hold a scalped-loaded holder or any sharp item in the same hand at the same time as other instruments.
- Use verbal warning to announce transfer of a sharp instrument.
- Use detachable sutures or safety devices to facilitate needle removal.
- Avoid finger contact with tissue being sutured or cut.
- Keep eyes on all sharp items in use until they are returned to the neutral zone.
- Replace the shield to the tip of a drain, or trocar using an instrument, and not the fingers.
- When a syringe needs to be refilled while injecting incrementally, the needle can be left in the tissue, the syringe removed and refilled, and then the syringe reattached to the needle.
- When removing the needle from a suture, park the needle safely or protect the needle tip with the needle holder.

Most injuries (56%) happen to nurses and ORP. More than 80% of contamination incidences involve a penetrating wound with a sharp instrument, most are needle-stick injuries and they often go unreported. About 30% of needle-stick injuries are self-inflicted by the person handling the needle. An estimated 39% of scalpel injuries are self-inflicted, and some occur when a scalpel is being passed between personnel.

More than 30% of hepatitis B infections are transmitted by needle-stick injuries, a rate that is six times more frequent than in HIV infections.

1.2.5 Security in the OR

Security in the surgical areas can be focused on three pillars:
- Patient
- Surgical team
- Procedure

Patient
Staff culture should aim at disclosing all adverse events which can occur during a patient's stay in hospital. For this reason it is essential to compile a program for risk management which allows (when there is notification of an adverse event) the incidence to be recorded, trends to be evaluated, causes established, and the impact of the consequences to be assessed. These measures aim at making improvements and preventing a recurrence.

This practice is particularly important in the OR where patients are subject to an unfamiliar environment and are in a vulnerable situation during anesthesia when they are unable to defend themselves and question staff actions.

Surgical team
Security and safety for the surgical team has two goals, namely staff health and staff training.

Staff health management should be directed to the prevention of injuries and diseases to which individuals are exposed within their work environment. The main aim is having a healthy workforce who neither needs time off work for sickness nor is at risk of transmitting disease to or being infected by a patient in their care.

A comprehensive health program should include:
- Immunization program (hepatitis B, influenza)
- X-ray monitoring program
- Program for the prevention and treatment of injuries by punctures
- Overexertion prevention program

Formal training is aimed at achieving staff competence, where competence is defined as the ability to act responsibly and efficiently, to produce a result that satisfies a patient.

Achieving competence is about developing skills and knowledge which can then be used, transferred, and integrated with those of others to build a safe and informed "work style."

A training program should aim to determine the competencies required for the job, assess the educational and training needs of the individual, and then provide an appropriate training program to fulfill those needs. All such programs must be formally planned and evaluated.

Procedure
A surgical procedure is a series of linked processes, some of which are immediately apparent while others involve largely unseen support services, such as the procurement department for the ordering of implants and sterile services for processing instruments. It is important that the entire team have confidence in every step of the support process.

This particularly applies to the provision of sterile instruments which must not only be correctly cleaned and sterilized but also properly maintained. It is important to ensure that correct and complete instrument sets are ready for each operation.

Equally important is the availability of sterile implants for fracture management. With a trend toward prepackaged sterile implants in some countries, sterilization is becoming less of an issue than ensuring all necessary equipment is available before starting a procedure.

Authors   Rossana Fornazzari, Myriam Sanchez

1.2.6   Conclusion

In summary, ORP performance requires the alignment of many factors, particularly communication, surgical instruction, environment considerations (which must consider the safety of the personnel as well as the patient), and development of technical skills to perform the surgical activity.

All these aspects must be developed within a formal structure which balances these factors to produce a secure environment for the patient and high-quality practice.

1.2.7   Further reading

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Acknowledgment

1.3 Environment

Author   Christine Booth

1.3   Environment

Invasive procedures are performed in the operating room (OR) to improve the physical condition of the patient. These may range from minor to acute life- or limb-saving operations. Although some of these may seem trivial to operating room personnel (ORP), even minor procedures are important life events to the patient.

The design, construction, and location of the OR are paramount to deliver safe, efficient, and effective care.

This chapter explores the necessary requirements for a safe OR, including design, environmental control, and cleaning.

1.3.1   Prerequisites

In the past ORs were different to those of today. Early operations were performed by surgeons in their outdoor clothes in totally unsterile conditions, often watched by a large audience of observers (hence the term "operating theatre").

With the advent of antibiotics and an understanding of the need for asepsis and sterile conditions the prognosis for patients began to improve.

The objective of modern OR design is to provide optimal conditions for patients and staff.

Design
When building new ORs many factors have to be considered, but there are several guiding principles that determine design:
- Location
- Requirements of asepsis
- Patients and staff safety
- Efficient use of resources

Location
The OR should ideally be positioned in a terminal location to minimize unnecessary passing traffic by visitors, patients, and staff. It should, however, be accessible to services such as the emergency department, intensive care, and other specialized departments. Good access to surgical wards is also necessary to facilitate the transport of patients to and from the OR. Long distances between wards and OR can result in long delays fetching patients, and long transfer times along corridors and in elevators with postoperative patients increases the risk of postanesthetic complications while in transit. Proximity to sterile services departments should also be considered. However, some hospitals now use off-site sterilization facilities.

It may be necessary to have ORs in more than one location within a hospital to facilitate all the above considerations, for example, having trauma ORs located next to the emergency department. This gives rise to a debate on efficiency and cost-effectiveness; some would argue that having all ORs in one location allows more efficient use of resources. A central storage area can serve all ORs within one department, while duplication of supplies is needed if ORs are located in different areas of the hospital. Rotation of staff can also be more difficult if ORs are not sited together.

The location within the building must also be decided. Historically, the top floor of a building was not considered an ideal location as it has the highest deposit of dust particles as dust transported in the atmosphere tends to rise with hot air. With the advent of modern ventilation systems this is less of a problem in modern buildings.

Whether designing a single OR or an OR suite, the principles remain the same. ORs must comply with the requirements of asepsis, they must create a safe environment for patients and staff, and use of resources must be efficient.

Asepsis

The requirement for asepsis is at the heart of OR design, and dominates all other considerations. The underlying principle for asepsis is the separation of clean and contaminated areas. There are various designs that achieve this but all work on the basis of segregating "clean" and "dirty" areas within the department. The risk of cross-contamination between these areas is minimized by good design.

Operating suites are divided into "zones" which are designated by the activities carried out in them.

The outer or reception area is located at the entrance to the OR department. Staff and visitors can access this area in outdoor clothes, supplies can be delivered, and patients enter and leave the department at this point.

Access to changing areas should be from this reception area, with a separate exit into the clean area once staff and visitors have changed into OR clothing (Fig 1.3-1).

Individual department layout will vary greatly between hospitals; however, in all cases ORs themselves and instrument storage areas should be the cleanest areas. All unnecessary traffic must be avoided, and ventilation systems (described below) designed accordingly.

Supplies and equipment should be stored adjacent to the OR in which they will be required. Some equipment, such as microscopes, attachments for trauma operating tables, and monitor stack systems for endoscopic procedures, are bulky and take up space and should be stored outside the OR.
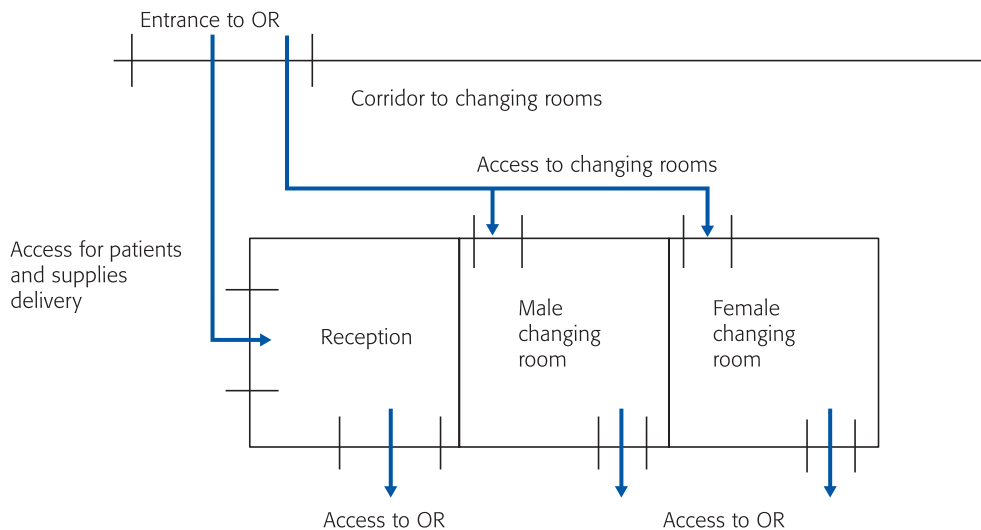

Fig 1.3-1   Access to operating rooms.

Author   Christine Booth

OR equipment is delicate and expensive. Inadequate storage facilities lead to damage which is not only costly but can also delay surgery while it is being repaired.

There also needs to be a "contaminated" area within the department. This area must be clearly and physically separated from the surgical area. This is where decontamination and reprocessing of instruments is performed and contaminated waste from the OR is disposed.

Also located within the department will be a postanesthetic care unit. This should be accessible to all ORs within the department. Entrance for patients will be from the clean area, and a separate exit should be available to return patients to the wards.

Safe environment

The surgical team is responsible for delivering high-standard care to patients; to achieve this, optimal conditions must exist. The surgical environment must be safe for both patients and staff, hence the mental and physical safety of both groups must be considered during design. Space should be used in an efficient way, and work surfaces need to be created so that physical stress due to excessive lifting is reduced.

Efficient use of resources

The way in which the OR is designed should help the team to obtain best results with a minimum of energy, with consideration given to minimizing both capital and running costs. Intelligent design limits the flow of people past the OR and reduces unnecessary movement of staff and equipment within it.

1.3.2   Architectural structure and design

To obtain best results, the design team should be multidisciplinary. This group should include surgical and OR staff, representation from the infection control team, hospital engineering and maintenance staff, and members of the domestic (cleaning) team. All members should be able to offer valuable input, using their practical and professional knowledge. The architect should also be familiar with the special requirements of designing an OR including the need for high acoustic, thermal, and lighting standards.

In addition to requirements of asepsis, safe environment, ease of maintenance, and efficient use of resources, other considerations exist that will influence the architectural structure.

The proposed use of the department is important, the number and type of procedures to be performed, the number and diversity of specialties using the OR, the proportion of elective and emergency procedures, and the usage hours must all be considered. Departments used for a large proportion of same-day (day-case) surgery have different requirements to those used for major surgery. Often day-case departments are separate units due to their specific needs. Additional patient waiting areas are required and the size of the OR generally does not need to be as large as those for more complex surgery.

Budget, hospital capacity, local environment, future expansion capabilities, and technical progress will also influence the design and location of an operating suite.

If an operating suite is to be extended rather than newly built, then plans have to be made to ensure minimal disruption to continuing work within the suite. If it is impossible to close the suite during renovation then the work area must be totally excluded from ORs still in use. Safety of patients and staff must remain paramount at all times.

OR size

The dimensions of the OR must be decided (Fig 1.3-2). This depends to some extent on the type of surgery to be performed within it. For example, an OR intended for use in trauma or orthopaedic procedures need to be larger than one for minor general surgical procedures. This is due to the amount of equipment and instrumentation required; trauma traction tables, image intensifiers, and video stacks for arthroscopy. Joint replacement and trauma surgery often require large numbers of instrument sets, which means the "sterile field" occupied by the scrub practitioner, surgical team, and instrument trolleys is a larger area than for a simple "one-set" procedure. Room is needed for the "circulating" staff to perform their duties without compromising the sterile field. Consider whether a square or rectangular OR is most suited for its required purpose.

Floors

OR flooring should be:

- Smooth
- Hard
- Seamless
- Nonslip
- Antistatic
- Nonporous and stain proof
- Curved at the wall-to-floor junction

All the above comply with safety and asepsis. It is essential that the material used for flooring is easily cleaned and maintained. Flooring should be hard enough to withstand repeated use from heavy equipment. Smooth flooring is less likely to hold dirt and is more easily cleaned, although for health and safety reasons it must have a nonslip surface. A curved junction between the wall and floor and the extension of the flooring material up the wall also facilitates cleaning.

Fig 1.3-2 Operating room.

Author   Christine Booth

Walls

Walls and ceilings should be:

- Nonporous surfaces
- Free of joints and crevices
- Nonreflective
- Fire resistant
- Easy to clean
- Consideration given to color
- Rounded wall-to-ceiling junction

It is important that walls are free from joints and crevices, as these can harbor dirt and be difficult to clean leading to an increased infection risk. Wall covering is important; while painted plaster walls give a smooth, easy-to-clean surface they are easily damaged, revealing bare plaster which is porous and impossible to clean effectively, making it the perfect breeding ground for bacteria and spores. Laminated wall cladding up to a height of 1–1.5 m prevents such damage and is nonporous and easy to clean.

If walls are painted, nongloss paint should be used to reduce glare. Choice of color is also important. Some colors, combined with artificial lighting, can alter perception of patients' skin color which can be a problem, especially in anesthetic rooms and postanesthetic care areas. The choice of light bulbs and fitting can have a similar effect.

Doors

Ideally doors should be sliding, electrically operated, and hermetically sealed. This type of door helps to ensure that the correct air pressure is maintained in the OR. Doors which swing open cause greater disruption to the air supply. It is a mandatory requirement in some countries that doors are lead lined if x-ray is to be used in the OR.

Storage

Easy-to-access storage space for large items of equipment is needed within the clean area of the department as well as adequate space for the storage of sterile instrument sets and sterile implants. Storage space is required in each OR for the consumables and other sterile items which are needed during surgery, for example sutures, swabs, or dressings. Any type of storage cart located within an OR should be of a closed design to reduce risk of contamination to items stored in it.

Lighting

Lighting within an operating suite must be adequate for everyone's requirements. The level of light should remain constant throughout the suite with no dark areas or shadows.

Windows are not generally fitted into ORs as they may be distracting. Variations in transmitted light because of outside weather conditions produces inconsistency in room lighting, while glare from windows can also interfere and distract when using video screens and microscopes.

Windows in staff rest areas are a good idea, as they allow natural light to be accessible to staff during their working day. However, these should not be opening windows so as not to disrupt ventilation within the department.

Fluorescent lighting is the usual choice, as the light produced is generally uniform, does not cast shadows, and produces less heat than other varieties. Bulbs are available in different colors and the choice should be to produce as near daylight conditions of lighting as possible. Bulb color should be consistent in all areas of the department to avoid surgeons and anesthetists having to adjust to different conditions. For example, lighting in anesthetic induction rooms should be the same as the general lighting in the OR as the skin color of a patient can look different under different lighting conditions.

Ceiling lighting should be flush fitted to avoid dust collecting on hanging fitments. A dimming device should be available in each OR to enable the general lighting to be lowered when necessary,

such as when performing an arthroscopic procedure to enable a better view of the TV monitor.

The operating lamp must provide an area of bright light free from shadows; the light should be large and easily movable in all planes. Many modern operating lamps use light-emitting diodes (LEDs) which produce a high-quality light. The quality of the operating lamp will impact directly on the effectiveness and efficiency of the surgical team—consideration should be given to the type of surgery, for example, depth of cavity. The focus of the lamp should be adjustable to allow a greater intensity of directional light as required. In trauma and orthopaedics, two operating lamps often give better illumination of the operative field than a single one.

It should be possible to attach sterile light handles to enable the surgical team to adjust the direction of the operating lamp during a procedure. This minimizes the risk of circulating staff compromising the surgical field while adjusting the lamp. Some surgeons may choose to use a head lamp in addition to the operating lamp to give greater directional control when operating in areas inaccessible to the main operating lamp.

Electricity, gasses, and vacuum

The provision of adequate power supply points is vital. Much of the equipment used in the OR is powered by electricity. Power points should be distributed around the OR in sufficient numbers to remove the need for multipoint extension leads. This not only minimizes the risk of trips and falls from trailing wires but also prevents the overload of sockets. Trailing cables can be minimized by the use of overhead pendants.

Emergency generators need to be available in the event of a loss of electricity. These are often located with the main back-up generators for the rest of the hospital rather than within the OR suite. They require regular testing to ensure function during an emergency.

The provision of anesthetic gasses, vacuum, and compressed air should be considered during design. Like electrical power points, these can be delivered via a pendant system suspended from the ceiling, minimizing the use of trailing cables and pipes, or via wall ports.

The location of the anesthetic machine should be considered. Whether it always remains in the same place or will need to move within the OR depends on the type of surgery. It may be advisable to have access to anesthetic gasses from several points for this reason. Each OR should have individual cut-off points for gasses. This not only enables maintenance work to be carried out in individual ORs but also is a necessary safety requirement.

Adequate provision of vacuum is required for both anesthetic and surgical use. In procedures involving severe hemorrhage, these two suction devices may be required by the surgical team, these should be available without compromising the vacuum supply to the anesthetic team.

Compressed air needs to be supplied to each OR. Air at 4-bar pressure is required for anesthetic machines and for pneumatic tourniquets, so ports should be sited to allow adequate provision for both. Power tools are driven either by battery or compressed air; if the latter, air at 7 bars of pressure is required. Again, outlet ports should be distributed within the OR to allow air hoses easy access to the instrument tables wherever they are positioned for surgery.

X-ray and IT equipment

Adequate x-ray viewing screens should be available in the OR, situated to allow good vision for the surgical teams during procedures. The increasing use of digital imaging may make the provision of large size computer screens linked to the hospital network necessary. Computers required for OR management systems are increasingly being installed in every OR.

Author   Christine Booth

Equipment

The range of equipment required in each OR depends on the type of surgery; however, in general, certain equipment will be standard to all.

Anesthetic equipment

This comprises an anesthetic machine, ventilation, and patient monitoring equipment. Additional equipment for anesthetic use varies dependent on whether there is a separate anesthetic induction room (Fig 1.3-3).

Operating table

The style of OR table depends on the type of surgery. Different tables are available for specialist use. For example, operating tables for trauma surgery have a large range of attachments and accessories for positioning purposes. All tables should have a pressure-relieving mattress covered by an impervious surface. The integrity of the mattress cover should be examined regularly and replaced if damaged to prevent leakage of fluid during surgery, as this poses an infection risk. Irrespective of the type of surgery or whether manually or electrically controlled, all operating tables must have the ability to place the patient in the "head-down" (Trendelenburg) position rapidly and easily in the event of an anesthetic emergency.

Trolleys and tables

Generally, stainless steel is the material of choice for instrument tables and other small trolleys. This material is durable, stain resistant, and easy to clean between procedures (Fig 1.3-4). This also applies to intravenous stands and bowl stands.

Fig 1.3-3   Anesthetic equipment in OR and separate induction room.
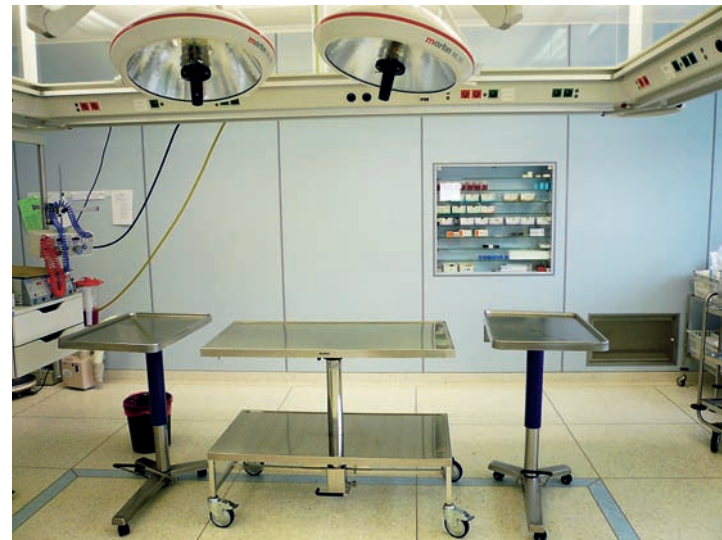
Fig 1.3-4   Instrument tables.

Storage carts

These are required to store items, such as swabs, sutures, that need to be readily available within the OR to prevent unnecessary movement of circulating staff during surgery. They should have closed fronts to prevent accidental contamination of stored items.

Receptacles for waste and reusable linen disposal bags should be available. These should be portable to provide easy transport to the contaminated area for disposal after each procedure.

Other general equipment includes sitting stools (or chairs), platforms to stand on, and diathermy and suction equipment.

1.3.3   Clothing

Clothing is important in the OR environment. *The Working Group Hygiene in Hospital and Practice* states that:

"Operating room (OR) clothing and patient draping materials must form an effective barrier against the spread of infection from both staff and patient to the wound and equally importantly, from patient to staff."

Each OR suite should have specific policies relating to dress code. All staff within the clean area of an OR must wear scrub suits. These should not be worn outside the OR suite, and must be changed if they become soiled. Hair should be covered by a hat and face masks worn. There is much debate regarding the effectiveness of face masks. Many institutions require that they are worn in the presence of an open wound or opened sterile surgical instruments. Some do not. However, the use of masks and protective visors or goggles by the scrubbed staff not only gives protection to the patient but also to themselves.

Shoes worn in the OR should protect the wearer from contamination by liquids. Shoes should be comfortable and supportive with enclosed toes and heel straps or enclosed backs. They must be cleaned regularly, ideally by machine.

Additional protective items, such as nonsterile gloves and aprons, should be available and worn by circulating staff as necessary. Lead aprons must be worn by every staff member within an OR, including the anesthetic team, whenever exposure to x-ray radiation is in progress. Specialized eye protection must be used during laser surgery.

Surgical gowns and gloves

Sterile surgical gowns and gloves are worn by scrub staff to protect both the user and the patient. They should be made from impervious material and may be disposable or reusable.

Patient drapes

The Working Group Hygiene in Hospital and Practice recommends that:
"Patient draping must prevent pathogens from the skin entering the surgical wound. Patient draping material should therefore be sufficiently resistant to withstand mechanical stress from instruments and personnel—even in the presence of liquids."

In general, patient draping material should be absorbent and impermeable to liquids.

Many hospitals now use disposable rather than reusable drapes. The use of cotton is all but discontinued as it is absorbent and offers little or no protection to patients or staff.

Author   Christine Booth

1.3.4   Ventilation

Ventilation is a major consideration in the design of operating suites. Ventilation is a means of removing and replacing the air in a space. Primarily, ventilation must provide a safe and comfortable environment for patients and staff. The link between air quality and surgical-site infection is well established; therefore, ventilation must reach the standards required to reduce risks to patients.

"Specialized ventilation for healthcare premises" in *Heating and Ventilation Systems* states that operating departments have the following specialized ventilation requirements:

- Remove, contain/dilute specific contaminants and fumes
- Ensure isolation of one space from another
- Preserve a desired air-flow path from a clean to a less clean area
- Provide control of the cleanliness of a space
- Provide control of temperature
- Provide control of humidity

Any ventilation system for an OR suite should ensure that the movement of contaminated air from a contaminated to a less contaminated or clean area is minimized. This is achieved by keeping the clean areas under higher pressure, which prevents the backflow of air into the clean area even when doors are open.

Air becomes contaminated in various ways:

- Through the air supply
- From room occupants
- As a result of work activities
- By transfer from adjacent spaces

Air contains microorganisms on airborne particles, such as skin squames, dust, lint, or respiratory droplets. The major contribution to contaminated air is from room occupants. Dead skin shed from room occupants can be minimized by restricting access to essential personnel only, the choice of clothing, and the room air-change rate.

Factors which determine ventilation requirements include:

- Activities, eg, extraction of odors, aerosols, vapors, fumes, and dust
- Dilution and control of airborne pathogens
- Thermal comfort

There are two main ventilation systems used within ORs. Conventional ventilation maintains a specific airflow between rooms even when doors are opened, while ultra clean ventilation provides a large volume of clean-filtered air to the zone in which the operation is performed.

Conventional ventilation systems: deliver atmospheric-filtered air under differential pressure. Air is filtered in the Air Handling Unit (AHU) and delivered by downward displacement. Transfer grills enable air to pass in either direction between rooms of equal pressure and cleanliness. Pressure stabilizers permit the flow of air in one direction only—from clean to less clean areas. Each area has a recommended air-change rate, the cleaner the area the greater the number of changes of air per hour. Air is vented through ducts to the outside atmosphere; some air is filtered and recirculated within the suite.

Temperature within an OR should be between 18° and 25°C. If the temperature of the room is too cold it can contribute to patient (and staff) hypothermia. Too high a temparature not only makes conditions for staff uncomfortable but also increases microbial growth. Staff should be able to control room temperature within these limits via a control panel located within the OR. This panel should clearly indicate the room temperature, the humidity, and status of the ventilation plant.

Ventilation supplied by conventional systems should provide the following number of air changes per hour at specified pressure:

Area	Air change/hour	Pressure (pascals)
Sterile preparation (lay-up room)	> 25	35
Sterile pack store	10	25
Operating room	25	25
Anesthetic room	15	> 10
Sluice/dirty utility	> 20	-5
Postanesthetic care	15	0

Ultraclean ventilation systems: significantly increase the effect of diluting contaminants performed by conventional systems. This is achieved by providing a large volume of clean-filtered air to the area in which surgery is performed and sterile instruments are exposed. This system, which is generally used for major orthopaedic procedures, such as joint replacement and fracture fixation, purges the clean area beneath it of contaminants. In addition, the pressure in the clean area prevents outside contaminants from entering.

The flow of air is unidirectional and is subject to higher levels of filtration. This ventilation system is not suitable for all types of surgery as the high airflow rate can lead to increased moisture loss from tissues. It has, however, significantly reduced surgical-site infection rates in orthopaedic procedures.

Humidity

Humidification was necessary in the past to control the risk from flammable anesthetic gasses. As the use of such gasses has now ceased, it is no longer necessary to maintain such strict control. It is acceptable for humidity to swing between 35 and 60%.

Waste anesthetic gasses

Anesthetic gasses are subject to workplace exposure limits and must be contained and removed by a suitable gas scavenging system. Some leakage occurs with all anesthetic systems, particularly during such times as patient transfer when breathing systems may be disconnected.

The air movement from the ventilation system should ensure that this leakage is diluted and removed from the atmosphere. Anesthetic agents are heavier than air; therefore, supply at high level with extraction at low level will minimize risk to staff.

Regular maintenance of ventilation systems ensure that they are functioning correctly. Engineering staff should monitor air change and pressure rates and have a regular program in place to clean/change filters and clean the ducts.

1.3.5   Environmental cleaning

In July 2004 the UK Department of Health published a report, "Towards cleaner hospitals and lower rates of infection," stating that: "A clean environment provides the right setting for good patient care practice and good infection control. It is important for efficient and effective healthcare."

Environmental cleaning is a team effort, and is the responsibility of both surgical and environmental services personnel. A clean surgical environment together with good ventilation systems and good technique from the OR staff help to reduce the risk of patients developing infections. Policies and procedures for environmental cleaning must be written down, reviewed regularly, and be readily available to staff. Each department will have its own policies, which may differ dependent on the type of surgery and local infection control guidelines. The following is an example of cleaning requirements.

Author   Christine Booth

General

- Surfaces such as operating tables and any other equipment in direct contact with patients must be cleaned with detergent between cases to reestablish a safe, clean environment for the next patient.
- Blood or other contaminants on the floor should be dealt with as soon as possible.
- All areas, OR, anesthetic induction rooms, and general areas should be kept free from clutter to aid cleaning.
- Items should not be stored on the floor. Failure to store items on shelving or racks impedes floor cleaning and can lead to build up of dirt and dust.
- ORs should be visibly clean and dust free.
- Ventilation grilles in walls or doors should not be obstructed or occluded.
- Storage of supplies and consumables should be kept to a minimum to aid stock rotation and prevent accumulation of dust.
- The fabric of the OR suite should be in good repair. Any defects, damaged walls, or floors should be reported and repaired.

Daily

Floors should be cleaned with floor-scrubbing machines using an approved detergent and water. This should be done at the beginning of each day and again once the day's operating is finished. The whole of the floor including edges and corners should be cleaned.

All horizontal surfaces and fixed equipment should be damp-dusted using a lint-free cloth. Lint-free cloths should be used for all cleaning to avoid fiber loss. Lint cloths can lead to fiber deposits which remain on surfaces after cleaning and can lead to additional dust contamination in the atmosphere.

All other fixtures, including operating lamps, should be cleaned with an approved detergent ensuring that a thorough check is made for splashes and contamination.

Instrument trolleys should be cleaned by hand or processed in a washing track before and after each use.

When mops are used they should be color coded or marked to reduce cross-contamination from one area to another. Mops should be stored in a designated area. They should be stored with mop heads upright to allow the mop heads to airdry; buckets should be emptied, washed, and stored inverted after use. Used mop heads should be returned to the laundry or discarded if they are of the single-use variety.

All areas, OR, sterile preparation areas, anesthetic induction room, scrub room, and utility room should be completely cleaned daily.

Maintenance schedule

While walls should be cleaned of spills and splashes daily, there should also be a planned program for cleaning wall and ceiling. This should be done by environmental cleaning services and should occur at least every 6 months.

This must be completed in planned downtime for each OR. This could be at night or weekends when the OR is not in use. For emergency/24-hour ORs, time must be scheduled when surgery can continue in another OR. Any planned maintenance or repairs can also be carried out during downtime.

1.3.6 Staff

Staff members are the most important resource of a department. Irrespective of architectural design, how old or new the suite is, how much or little equipment and technology is in place, no department functions effectively or efficiently without cooperation and teamwork. Not only the fabric of the building needs maintenance and attention but also the staff. Specialist skills need to be taught and learned—experienced staff are a valuable asset, whatever their grade. Training programs and educational resources should be available to enable staff to achieve the common goal of excellent patient care. Patients are entrusted to the medical team during surgery, and all staff—ancillary, domestic, maintenance, scrub, circulating, recovery, surgical, and anesthetic—play a part in the provision of this care.

1.3.7 Further reading

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Acknowledgment

1.4 Instrumentation

Author   Isabel van Rie Richards

1.4   Instrumentation

A surgical instrument is a tool designed to perform a specific action during a surgical procedure. A surgical implant is designed to be left in the patient to perform a specific function (eg, fixing a fracture). All medical devices whether instruments or implants have to comply with a number of governmental and international regulations and standards to guarantee they are fit for the desired purpose. Medical devices are aimed at improving the medical condition of the patient and facilitating the surgical procedure. Their use must also qualify as safe for both the patient and healthcare professionals.

This chapter explains standards of care and maintenance of instruments in the preoperative, intraoperative, and postoperative phases. Standards for the decontamination process as well as guidelines for the organization and planning in the operating room (OR) are presented.

1.4.1   Preoperative preparation

Acquiring information

Information for an operation must be acquired before the procedure. Surgeons give the team details of the operation to be performed. They must provide clear and adequate information including the name, gender, age and general condition of the patient, the nature of the injuries, and the type of operation. Surgeons must also inform the operating room personnel (ORP) of the patients' wishes. Checklists and a good general knowledge of the OR allow the team to prepare the instruments, equipment, and implants required for the procedure. Communicating with each other and obtaining this information is the key to effective preparation and a successful operation. Moreover, mutual respect for the patient and team members is imperative. Strengths and weaknesses of individual staff members must be identified and noted so that, if

necessary, any deficiency in knowledge or professional experience can be compensated. When this is evident, additional training and information must be provided.

Preparing the operation
Setting up material

Operating room time is the most expensive resource in a hospital. Having adequate, proper functioning instruments, and equipment ready at hand enhances patient safety, prevents delay, saves money, and increases staff and surgeon satisfaction and is therefore important. The selection of equipment depends on the patient, the operation, the surgeon's preferences, and the equipment availability. Sets, instruments, and implants are prepared and set up according to institutional practice.

Each hospital should have checklists to simplify the task of the ORP when setting up for surgery, especially for emergency cases when items may be forgotten due to stress, or be performed out of hours by ORP unfamiliar with the procedure. These checklists should be regularly updated and all items correctly and clearly identified and labeled to simplify the setting-up process.

When an instrument set is on loan, it must be checked to ensure it is complete. On arrival in the OR, the transport packaging of the sets must be removed. As the material is usually not sterile at this point, the recipient must then check the contents to ensure nothing is missing or damaged. It is also highly recommended that the scrub ORP for the procedure and surgeon become familiar with the instruments and their order of use during surgery before it is sent for sterilization. In exceptional situations the set on loan is sterile on arrival (eg, when the set is borrowed from a neighboring hospital). In this case the sterile integrity of the set is mandatory and a thorough check of the contents is done preoperatively.

Checking and preserving integrity of sterile instruments

Once the decontamination and sterilization processes have been completed, the sterile sets are stored. The method of packaging, handling, transporting, and storing instruments determines the shelf-life of the material. Shelf-life is the length of time that a device is considered to remain safely sterile before its packaging integrity might have become compromised. It is not possible to give a general recommendation for the shelf-life of all sterile items because of the large variation in methods of packaging and storage.

All devices for sterilization must be packed using materials that are resistant to liquids and bacteria and maintain the sterility of the contents. The penetration of moist heat (steam) through the packaging permits the sterilization of the contents. Other methods of sterilization use gasses, such as ethylene oxide, formaldehyde, or plasma. High-dose radiation is used by some companies for single-use items but is not practical for resterilization of equipment. The choice of packaging depends on the content's weight and shape. Heavier and longer instruments and sets are usually sterilized in metal containers; lighter and smaller items are wrapped in double sterilization paper or in pouches. The significance of the double wrapping is to facilitate the way the sterile contents are presented to the scrub nurse. Packaging with cotton linen is not recommended as it does not act as a barrier against microorganisms especially when there is contact with liquids. Cotton may be used as a protective layer only to prevent perforation of the packing paper. Sharp and pointed instruments must be protected so that damage caused by manipulation during sterilization process, transport, or storage is avoided. The packing and wrapping process must be performed according to institutional guidelines, meet national and international standards and is completed by using either suitable tape for wraps, a sealing procedure for pouches or locking tags for containers. The use of sterilization tape has a triple function. First, it closes the packaging. Second, the tape indicates that the product has passed through a sterilization process due to a color change on the tape; however, it does not prove that the sterilization process has been successfully carried out. Third, the tape also functions as a seal for the package. If the tape is not intact before use the packaging must be considered not to be sterile.

Each and every medical device must at all time, before, during, and after sterilization be handled with care. Heavy instrument trays should not be placed on lighter or fragile instruments. Maintaining the integrity of sterile supplies during transport is also important. During transportation trays and instruments must be protected in a closed container or trolley to reduce the risk of accidental damage and exposure to dust and other external influences. Storage of surgical instruments must also meet defined criteria and standards. They must be stored in a dry room, free of airflow and UV-light; and at a temperature between 20° and 25°C. The instruments should never be exposed to extreme temperature changes. In the storage room heavier trays should be stored on lower shelves and lighter devices on a higher level. If there is a lack of storage room and heavier items must be stored at a high level then the use of a mechanical lifting aid can facilitate the transfer. Stacking of containers is not recommended; unnecessary moving and shifting of containers is not ergonomically ideal and can cause back pain. Besides, the airflow produced by the excessive movement of sets must be limited to minimize the build up of dust particles in the storage area. Respecting the first-in first-out principle avoids regular expiry of sterile items. Regular checking of expiry dates and package integrity is obligatory. Nonsterile equipment must be stored in a different place or rather a different supply room than the sterile equipment.

Setting up the OR

Setting up the OR is the step that follows selection of the materials to be used for an operation. In most cases the scrub ORP prepare their own trolleys. Number of trolleys, equipment, containers, instruments, and implants necessary for the particular operation are organized within the OR so that work can be performed efficiently. The type and side of operation, for example, determine how trolleys and equipment are positioned and organized. All trolleys are placed beneath the laminar air flow. Sterile equipment

Author   Isabel van Rie Richards

is kept separate from nonsterile equipment and liquids necessary for rinsing and disinfecting the surgical-site. Equipment not needed for the operation should be removed from the OR, although medical records and x-rays of the patient should remain.

A final check on the integrity of all sets must be performed before unpacking. The wrapping or packaging must be undamaged and dry, tapes and locking tags intact, and tracing labels valid. The circulating ORP finalizes room set up and is responsible for presenting all material as it is required in a sterile and logical manner to his/her colleague. A good knowledge of the procedure and paying close attention to the operation is thus a prerequisite. The circulating ORP is also responsible for the continuous supervision of aseptic technique and needs of the patient. In a good team, the expertise of both scrub and circulating ORP complement each other.

The circulating ORP has to complete all administrative documentation. The scrub ORP will check and approve it. A count of all instruments, swabs, needles, and other small items should be done before and after surgery. Closing the wound at the end of surgery must be stopped if the second count does not match the first one. The scrub ORP organizes the sterile instruments on the table according to their use and the steps of the operation. Missing instruments will be reported and, if available, immediately replaced. If one or more instruments are contaminated the whole set must be discarded and needs to undergo a further decontamination cycle. Each incident of a missing, damaged, or unclean instrument must be reported so that the problem is avoided in the future.

1.4.2   Intraoperative care

A professional scrub ORP makes a major contribution to minimizing the operation time through efficient team work, the practice of strict asepsis, and thus improving the patient's health status and reducing the risk of complications, such as surgical-site infections. He/she should be able to think and work at least one step ahead of the surgeon and anticipate the surgeon's needs. This requires a sound working knowledge of the entire procedure and its possible complications as well as concentration, discipline, and a systematic approach.

ORP are responsible for the care of the instruments. Experience has shown that regular and professional intraoperative care, correct use, and good maintenance of instruments significantly increase the lifetime of each item. For example, ORP should object to any unprofessional and incorrect use of an instrument by the surgeon, such as hammering on the universal chunk.

If time allows, it is highly recommended to clean instruments as the operation proceeds. This ensures good instrument function (an instrument covered with a thick layer of blood may not work properly) and will simplify the decontamination process afterward. Excessive blood should be wiped off, the lumen of hollow instruments flushed, and bone debris in reamers, drill bits, and taps removed. Damaged instruments should be separated from the set and identified for repair. All parts of a broken instrument and each part of any removed implant (plates, screws, and washers) must be identified and counted. At the end of the operation the scrub ORP removes all sharp items and places them in a special container which can be irreversibly locked; disposable material is discarded. All instruments are returned to their correct sets and placed in closed transportation containers. Depending on the local policy all instruments should be dismantled and opened to facilitate the decontamination process. When stacking several sets, special care must be given to individual instruments. Heavy trays and instruments must be placed at the bottom, lighter ones

on top. Be careful also not to crush delicate optics, lightcords, or electrosurgical cables.

Unused sterile material, if their integrity has not been compromised, can be returned to their standard place of storage.

Precise documentation of all implants used is noted and (according to institutional practice) reordered. If nonsterile stock of implants (eg, screws or plates) is available, the set must be replenished before the decontamination process starts so that the invisible layer of dust and any soiling on the surface of the implant is removed before sterilization.

During the whole operation the OR team must behave in a correct manner. Doors must be kept closed throughout the surgery to guarantee optimal function of the laminar flow. Unnecessary movement of personnel must be avoided. Nonsterile personnel approaching the surgical-site or sterile trolleys and equipment must keep a minimum distance and stay outside any laminar flow canopy.

When the operation ends attention must focus on transferring the patient. Only after the anesthetist and his/her team have been given the required support and the final briefing of the operation has been accomplished may the nursing team prepare the room for intermediate or final cleaning.

1.4.3 Postoperative care

Reprocessing the instruments starts as soon as the material arrives at the central sterilization unit. All steps which an instrument goes through, from use to reuse, are illustrated in the lifecycle of instruments (Fig 1.4-1). Each step must be fully completed to guarantee sterility. If conditions are not satisfactorily fulfilled during any one of the phases, the instruments must be considered nonsterile and the total decontamination process must be repeated.
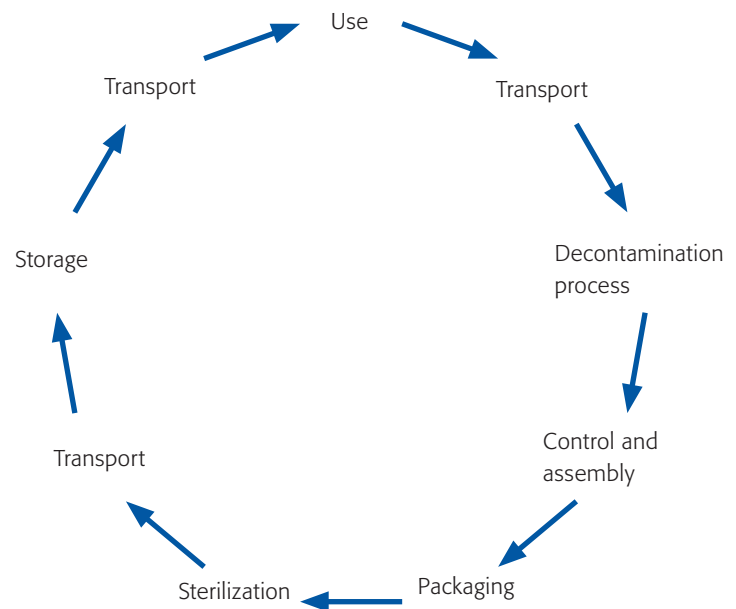
Fig 1.4-1   Lifecycle of instruments.

Author   Isabel van Rie Richards

Decontamination process

Decontamination is a strict and standardized procedure. It is a combination of processes which includes cleaning, disinfection, and/or sterilization to make a medical device safe for further use. The aim is to maintain the functionality of the instrument and to reduce microorganisms, soiling, chemicals, corrosion, and other potential debris on the surface of a device so that it is hygienically safe for the patient and the OR team to use. Quality assurance of this process reduces the risk of infection.

Corrosion may be a consequence of an incorrect decontamination process. High-quality surgical instruments are resistant to corrosion (see chapter 1.5). This resistance to corrosion depends on the condition of the passivation layer on the surface of the instrument which protects the underlying metal. This layer can be destroyed by mechanical, chemical, or thermal damage due to unprofessional handling.

The material an instrument is made of determines the type of decontamination process needed.

Only reusable products should reenter the decontamination cycle. Even though some disposable items can be disinfected and sterilized, reusing them is prohibited. They can be damaged by their first use or by the resterilization process.

Consulting the instruction manual of an instrument is recommended before it enters the recycling process as some instruments, particularly cameras and power tools, have special requirements for decontamination and maintenance, and can be seriously damaged if these are not carried out.

Sorting of material

The decontamination process starts with an initial cleaning immediately after use. All instruments and sets are then sorted for manual or automated cleaning and disinfecting.

The instruments must be handled with care so that damage and self-inflicted injuries are prevented. Instruments with several components must be dismantled (although there are exceptions, such as those for power tools which must be washed closed and sterilized open). Material unsuitable for machine washing needs to be separated. Sharp instruments must be placed in a separate tray. Cannulated instruments are checked for forgotten guide wires or remaining foreign particles. Corroded instruments are removed as they may "contaminate" other instruments. Damaged instruments should, if repair is not possible, be disposed of in a sealable rubbish container. Instruments for repair must be fully processed before servicing. Overloading trays and crushing of delicate instruments must be avoided.

Personnel involved in the decontamination process have to protect themselves by wearing suitable protective clothing. This includes hat, mask, goggles or visor, water-repellent apron with full protection of the arms and body, and strong vinyl gloves (Fig 1.4-2).

Fig 1.4-2   Personnel protection.

Cleaning-disinfection procedure

Cleaning means when all visible debris on the surface of the instruments, such as dust, stains, blood, tissue, and other material, is removed.

Disinfection is the removal of pathogenic organisms from a surface which may cause infection.

Four factors are essential for an adequate cleaning-disinfection procedure:

- Water
- Mechanical action
- Chemical action
- Heat

- **Water** is necessary to remove major soiling from instruments.
- **Mechanical action** to remove soiling involves wiping, scrubbing, flushing, or vibration using ultrasonic waves. Mechanical action during an automated process is provided by flushing and spraying.
- **Chemical action** is provided by detergent mixed with water to kill pathogens. Fat and proteins are dissolved by detergent. The detergent may contain additives to protect the surface of instruments.
- **Heat** improves the dilution power of water and detergent. The correct temperature must be chosen to optimize the cleaning-disinfection procedure. If the temperature is higher than 45°C, blood and tissue residues tend to coagulate. Alkaline detergents, however, need a higher temperature to hydrolyze the proteins.

The washing procedure finishes with a thorough rinsing and drying to fully remove any remaining debris and detergents. Rinsing, preferably done with high-quality water (low in minerals), will reduce the risk of stains on and corrosion of instruments.

Automated cleaning

Automated decontamination has the advantage over a manual technique that it can be validated and limits the risk of incidents to personnel. Validation is a documented procedure for obtaining, recording, and interpreting results required to establish that a process consistently yields products which comply with predetermined conditions. The entire process is clearly defined with measurable criteria. To meet these criteria, accurate and regular quality controls must be performed.

The automated cleaning is carried out with a washer/disinfector. A washing cycle is followed by disinfecting. Careful loading of washing trolleys to expose all surfaces of instruments is extremely important.

First, the load is rinsed with cold water so that all major soiling is removed. Detergent is added during the cleaning procedure and the temperature chosen according to the type of detergent used. Usually the temperature remains below 45°C, although alkaline detergents require higher temperatures. If alkaline detergents are used then the water is neutralized to prevent corrosion. The duration and temperature of disinfection depend on the load but last up to 10 minutes at approximately 90°C.

Finally, the drying procedure will limit recontamination of the surfaces, as well as minimize the risk of corrosion and formation of water spots.

There are several types of washer/disinfectors. One example is the tunnel type (Fig 1.4-3) when all contaminated equipment enters the machine on the unclean side of the central sterilization unit and then leaves the washer/disinfector on the clean side disinfected, and dried.

All washer/disinfectors offer several programs according to different types of instruments and loads. They are user friendly and can

Author   Isabel van Rie Richards

deal with a high-load capacity. The tunnel-type washer/disinfector is divided into compartments, with each part of the cycle carried out in a separate compartment.

Manual cleaning

Manual cleaning should be restricted to those items which cannot be processed in automated cleaners. It is difficult to remove dry blood and tissue residue from instruments, so performing a "quick clean" intraoperatively and immediately after use is highly recommended. If material cannot immediately undergo the final decontamination procedure it can be immersed in an appropriate detergent solution, for a predetermined length of time, or it can be flushed under running water. Any splashing should be avoided. Proteins coagulate at 45°C, so the water temperature should be below this.

In some countries manual cleaning is the only option. Some tools can help to make this process easier. Brushes, with soft or hard bristles, available in different sizes and forms, can be used to remove debris from the instrument's surface or the lumen of hollow instruments. The use of metal brushes is prohibited as they can damage the passivating layer of the instrument. Sponges and towels should be used for more delicate instruments.

Spray guns are an effective way of cleaning the lumen of hollow instruments (Fig 1.4-4a). Different nozzles are available and can be chosen according to the instrument and the surface which has to be cleaned (Fig 1.4-4b).

After cleaning, all instruments are rinsed under abundant high-quality water. Suitable protective clothing must be worn at all times.

Fig 1.4-3   Washer/disinfector tunnel type.

a

b

Fig 1.4-4a–b
a   Spray gun.
b   Nozzles for spray gun.

Power tools

The type of power tool, the supplier, and the decontamination facilities in the hospital determine which method of cleaning to use. If an automated procedure is an option, then it should be used. If the power tools can go through an automated washer, then the hose connection or the battery contact plates must be covered with corresponding protectors.

Ultrasound cleaning

Cleaning is also done with ultrasonic waves. The waves of the ultrasonic cleaner break up any debris on the instrument surface, even if it is difficult to access, and thus allow a thorough cleaning of the device. The waves are produced by "shaking" the water with a frequency higher than that of sound. The temperature should be kept below 45°C.

When using ultrasound it is essential that the entire surface of the instrument is in contact with water. The use of the ultrasonic cleaner is recommended for small and delicate stainless steel instruments when an automated process is not suitable. Endoscopes, power tools, and cables of electric devices should never be immersed in the ultrasound or any other basin. Some components of these devices however, when made of stainless steel or other metals, can be immersed in water and thus in the ultrasonic cleaner. Softer materials, such as Esmarch bandages, absorb the waves and neutralize its function and are thus not suitable for the ultrasonic cleaner.

Control and assembly

Once the cleaning-disinfection procedure is finished the result is checked. If there is any irregularity the whole process must be repeated. Protective clothing must also be worn on the clean side of the sterilization unit when handling instruments and sets.

All equipment is inspected for soiling, functionality, damage, completeness, and to ensure it is dry. Wet instruments are wiped dry. Damaged, nonfunctional, and incomplete instruments have to be removed and replaced. Note, some instruments do not work properly at high temperature; these must be allowed to cool before being checked.

A more detailed check of instruments can be performed using a magnifying glass (Fig 1.4-5). Minor damage, corrosion, nonfunctional joints, and so on may thus be detected. If required, lubrication with the recommended oil can be applied. Surgical oil must be silicone free, have an antibacterial function, and be permeable to steam. The instruments are then loaded into instrument trays according to institutional requirements. Sharp and delicate instruments must be protected and not be crushed by heavier tools. Instruments with ratchets must be sterilized in an open (unlocked) position. Multicomponent instruments should be loosely reassembled. Once loading of the tray is finished an instrument tray-list is filled out, signed, and any missing instruments recorded.

Fig 1.4-5   Detailed control using a magnifying glass.

Author   Isabel van Rie Richards

Packaging

Containers which can be sealed with clips or tags are used for packing instrument trays. Wrapping and pouches are available for smaller sets or single instruments. The pouches chosen for single instruments must be appropriately sized and correctly sealed.

In all cases the outer packaging must indicate date of sterilization, expiry date, the contents, and all missing instruments or implants. Special markers and labels suitable for sterilization must be used for packaging.

Sterilization

The sterilization process is chosen to suit the equipment being sterilized. Moist heat (steam) is suitable in most cases. For a few pieces of equipment, gas sterilization is the only method suitable.

The whole procedure must meet numerous and strictly regulated criteria of a valid sterilization procedure. Regular quality control ensures good performance of the sterilizer. The sterilization cycle of each individual load is recorded. Any interruption of the sterilization process, whatever the reason, must be indicated and registered, and must lead to all the sets starting the whole process again from the beginning.

Because of the complexity of the whole decontamination and sterilization process and strict conditions which must be fulfilled, more and more hospitals prefer to outsource this task. Specialization of this process not only reduces costs but it also largely transfers the responsibility for validation and traceability. Dependence on external contractors has both positive and negative aspects, and surveys have shown that users are not always satisfied with the availability and condition of the returned instruments. In many cases the reason is poor communication between the hospital and the decontamination center.

All healthcare workers involved in the care and maintenance of surgical instruments have a responsibility to ensure the health and safety of themselves, patients, and others and help prevent the risk of infection.

1.4.4   Further reading

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Acknowledgment

1.5   Implants

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

1.5   Implants

The aim of implants in the treatment of fracture fixation is to restore the structural and functional integrity of damaged bone, while encouraging it to heal. Attaining this goal is dependent on a complex interplay of material properties, device design, physiological requirements, implant handling, and the patient's health condition.

1.5.1   Material   Nicola Kildea, Jessica Hayes

Materials used for fracture fixation implants include but are not limited to metals, degradable and nondegradable polymers, ceramics, bioresorbable calcium phosphate cements, and nonresorbable cements. New implant materials (generally within these classes) are continuously being researched and developed.

Implant materials used in internal fracture fixation must meet certain mechanical and biological requirements. Properties such as biological safety (biocompatibility), corrosion resistance, ductility, strength, stiffness, and fatigue behavior must be considered when choosing an implant material. Metal offers a good degree of these properties and is the most commonly used material in manufacturing implants for internal fixation. The metals used today in fracture fixation are either stainless steel, commercially pure titanium (cpTi), or titanium alloys, such as titanium-6% aluminium-7% niobium (TAN), and titanium-15%molybdenum (Ti15Mo).

Choice of implant material
The choice of material depends primarily on the requisite function to be accomplished and also on the manner in which the implant will be applied. The anatomical location and the required function (ie, high- vs low-load bearing, single- or multicomponent system) of the device will also determine the type of material to be used. Materials used for internal fixation must fulfil various fundamental mechanical requirements, the main considerations being stiffness

and strength of the material, its ductility, and importantly, its biopassivity. These are discussed in the subsequent chapters. Other factors, such as economics, implant availability, surgeon's preference, and patient needs and preferences may also be important in the final material used.

Stainless steel
Today stainless steel is one of the most frequently used biomaterials for implants in internal fixation. Stainless steel is a good implant material as it has excellent mechanical properties; it is corrosion resistant and cost-effective compared with other suitable metals (although this is no longer true for complex highly engineered implants, such as LCP and expert tibia nails when the cost of the material is small compared with costs of manufacturing and engineering each device). It also has an excellent record since it has been used successfully for many years in humans as an implant material.

There are studies, however, which show allergic reaction to nickel. Stainless steel is estimated to contain 1–2% nickel; although the clinical relevance of these is unclear. In contrast, cpTi and its alloys have the advantage of not containing nickel within the bulk material; therefore, nickel sensitivity is not an issue. However, recently new nickel-free stainless steels are being developed to address this issue, although these would be more expensive than conventional stainless steel.

Commercially pure titanium (cpTi)
Titanium has also been used as an implant material safely for many years. Because of cpTi's superior strength, corrosion resistance, acceptance by bone and soft tissue (good biocompatibility), superiority over stainless steel under cyclic loading and excellent biopassivity, cpTi has in recent years emerged in Europe (although not in North America, apart from with nails) as the forerunner in internal fixation devices. The density of unalloyed titanium is

lower than stainless steel. This decrease in density equates to a weight reduction of approximately 50% when materials of similar volumes are compared. This can make larger titanium implants more comfortable when implanted into the patient. Titanium also produces less image artefacts in magnetic resonance imaging (MRI) than steel.

Titanium alloys

One issue that surrounds the use of unalloyed titanium is its apparent weakness when used in high-load bearing regions. This concern has been overcome by the introduction of titanium alloys. In the last 25 years or so, TAN has come to the forefront. The microstructure of TAN provides improved implant strength compared with cpTi but it has decreased tensile strength and ductility. Consequently, titanium alloys, such as TAN, are not suitable for cerclage wire as the poor ductility means it does not have the malleability required for wire. Titanium alloys tend not to be used for areas that need a great deal of device contouring and manipulation due to the microcracking that can occur. In contrast, the high strength and low modulus of elasticity of titanium alloys are ideal for implants demanding high resistance to stress loading. The alloys have similar biocompatibility properties to titanium and produce far fewer MRI artefacts than steel.

Corrosion resistance

"Corrosion is an electrochemical process that results in the destruction of metal by the liberation of ionic metal."

Corrosion differs for single-component and multicomponent systems (ie, screw and plate). If tested as a single-element stainless steel—cpTi, TAN, and Ti-15Mo are all highly corrosion resistant, even in the presence of biological fluids. However, multicomponent systems are more challenging (Fig 1.5-1).

The ability of all these metals to resist corrosion is attributable to the oxide layer which forms on their surfaces (readily for titanium and its alloys). This passivation layer offers protection from the toxic elements found within the bulk of the material by preventing excessive diffusion of oxygen into the base material. The composition and the thickness of this oxide layer differ with any given material. Because of these differences, the oxide passivation film that forms on titanium and its alloys is more resistant to corrosion and thermodynamically more stable than the chromium oxide film that forms on stainless steel.

For internal fixation devices, the major form of erosion is fretting that occurs when micromotion between two adjacent implant components is encountered (such as when a screw head moves in relation to the plate hole). This micromotion can result in the production of small metal "fretting" particles into adjacent tissue, and if severe enough can cause failure of the fixation. With cpTi and its alloys, metal debris produced from micromotion generally results in relatively large metal particles (sizes in micrometer range) and often produces discoloration of the local surrounding tissues. In contrast, because of smaller particles produced by steel fretting (nanoparticulates), dissemination is often encountered and metal particles derived from steel can be found in the liver, kidney, and in the lymphatic system.

Fig 1.5-1 Corrosion of a stainless steel plate.

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

Ductility

"The ductility of a material is the degree of permanent (plastic) deformation it can tolerate before it breaks," or in other words the degree to which an implant, such as a plate, can safely be contoured. Materials of high strength, such as titanium alloys and cpTi, offer less ductility than steel. This means that generally a titanium plate cannot be bent or contoured as easily as a stainless steel plate. However, cpTi and its alloys have an elastic modulus closer to that of bone than stainless steel; thus, local stress concentrations on bone are reduced with use of these materials. Titanium plates should only be bent once to shape because over or multiple bending may cause a loss of strength in that area. It is recommended that surgeons do not bend preformed titanium plates.

Strength

Strength is the ability of a material to resist the application of forces without deformation. Thus, strength determines the level of load an implant can resist. "For internal fixation, the resistance of an implant to repeated load, which may result in failure by fatigue, is a critical issue." The strength of cpTi is approximately 10% less than steel; however, an increase of implant cross-section/thickness compensates for the difference in material strength. While steel is more resistant to single loads than cpTi, the latter is superior under more natural high-cycle repeated load.

1.5.1.1   Biocompatibility

This describes the suitability of a material for exposure to the body tissues or fluids within the site of application; ie, the way the body reacts to the implanted material. The body provides a hostile electrolytic environment that can lead to the corrosion of implants. Nonbiocompatible materials may cause the foreign body reaction with fibrous encapsulation and/or inflammation.

The manner in which material affects the body must be demonstrated through testing and analysis before they are approved by regulatory boards for implantation in the body. The major materials, outlined here that are used for fracture management implants today, are considered biocompatible and are approved for human use. However in reality no material is truly biocompatible. In fact, most material used to make orthopaedic implants have some toxic components but the naturally occurring oxide passivation layer on their surface helps shield these toxic elements from the body. They can all potentially corrode and cause complications inside the body. In general, cpTi and titanium alloys are considered to have better biocompatibility than stainless steel which is again attributable to the oxide layer of the material, and there is some evidence that titanium implants may be more resistant to infection than stainless steel ones.

Implant-tissue interface

The implant-tissue interface is the contact between implants to soft tissue and bone. There are different tissue reactions depending on what metal implant is used. To date, stainless steel implants are fabricated for clinics with a smooth, mirrorlike surface; while in contrast, cpTi and its alloys are produced with a standard microrough surface. This difference in the material surfaces produces diverse biological responses due to the resulting differences in their implant-tissue interfaces. Due to the smooth surface of stainless steel, micromotion within the implant-tissue interface may occur. This micromotion can lead to the formation of a thick and dense fibrous capsule with a liquid-filled void. The dead space provided by the capsule prevents access of any of the body's cellular defence mechanisms; providing a safe haven within the void for possible bacterial growth and infection. In some cases, however, the prevention of soft-tissue adhesion to an implant can be beneficial, such as in hand surgery when tendon gliding is required for free movement to occur over the implants. The movement of tendons is large (several millimeters) and this prevents the formation of a liquid-filled void. In pediatrics implant removal is more common and it is usually easier to remove current polished stainless steel implants than titanium implants (which are not currently polished) (Fig 1.5-2).
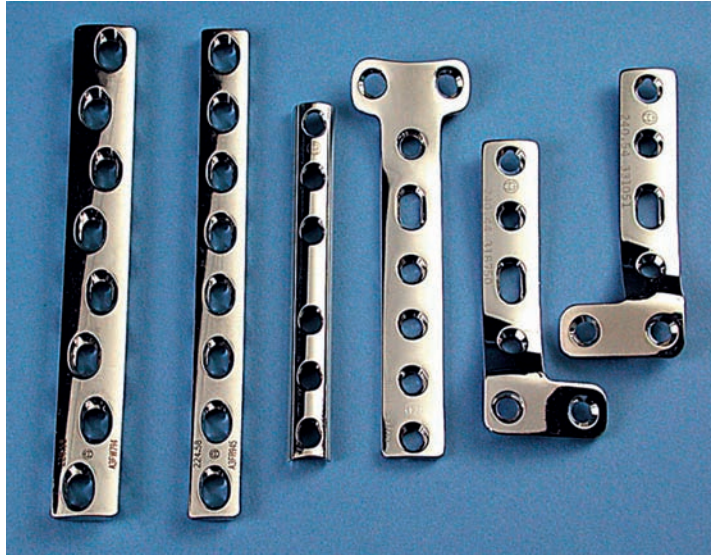
Fig 1.5-2 Highly polished surface of stainless steel implants.

In contrast, the surfaces of cpTi and its alloys (as currently used in clinical practice) promote direct tissue adherence to the implant, and generally do not form fluid-filled voids around the implant. This decreases the chance of infection, and increases the integration of the implant into the surrounding hard and soft tissues, which can make these implants difficult to remove (Fig 1.5-3).

The development of polished cpTi and cpTi alloy implants offer mechanical and biological benefits of these materials, but assessment of their ease of removal is ongoing. Selection criteria for implant material must be made on an assessment of each case, as both have advantages and disadvantages (Fig 1.5-4).

Fig 1.5-3 Dull surface of titanium implants.

Fig 1.5-4 Left to right: stainless steel, TAN, polished TAN.

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

Imaging

Magnetic resonance imaging (MRI) is an important diagnostic tool in orthopaedics and in many other facets of medicine as the information provided about structures and pathological entities is superior to that of conventional radiography and computed tomography. However, the effect of MRI on implanted metal devices has raised the issue of patient safety during insertion into the machine, especially as migration and dislodgement of pins have been reported. In addition, image interpretation can be severely affected by the creation of magnetic susceptibility artefacts. When attempting to visualize the area adjacent to the device, there can be focal signal loss, also known as a black spot, at the site of implantation which occurs due to distortion of the magnetic field by the metal. The sizes of these artefacts are proportional to the magnetic susceptibility as well as the mass of the implant.

Major differences exist between magnetic properties of stainless steel and cpTi and its alloys. Stainless steel reportedly produces artefact susceptibility 10 times higher than that of cpTi.

Other implants
Cobalt alloys

These alloys may be generally described as nonmagnetic, wear, corrosion, and heat resistant. They maintain high strength even at high temperatures. However, cobalt alloys are difficult to fabricate which is why, though they are common in joint replacement, they are not generally used in trauma surgery. Furthermore, cobalt metal ions have been shown to be among the most toxic and have been implicated in various adverse reactions, so their use in areas of high fretting in multicomponent systems is questionable.

Biodegradable implants

In some cases, metal implants may not be optimal for implantation. For instance, in CMF when anatomical contouring of metal is difficult, and/or the end requirement may be removal of the implant. In nonloaded areas such as these, when the limited mechanical properties of the polymers do not limit fracture stability, biodegradable materials may offer potential. After a certain period of implantation, this polymer becomes resorbed in situ, producing nonharmful by-products, such as H_2O and CO_2, which are then excreted from the body by normal metabolic routes. Biodegradable polymers are also being investigated as carrier scaffolds for controlled release of osteogenic substances to enhance bone healing or antibiotics for local delivery. However, fracture fixation is susceptible to infection and biodegradable material sometimes shows a reduced resistance to infection compared with the best metal implants, which is likely to limit their use.

Nonbiodegradable implants

Nondegradable polymeric implants, such as polyetheretherketone (PEEK) and polyetherketoneketone (PEKK) are also used in some specific areas because of their high resistance to the hostile physiological niche. However, these are extremely hydrophobic, that is they repel protein/cell attachment; therefore, without modification of the surface, changing it chemically or applying a coating, tissue integration will not occur. Furthermore, they are expensive to manufacture which limits their application. Their main use to date is for spine cages and patient-specific implants in CMF. Polymers such as PEEK are x-ray translucent and nonmagnetic; thus not heated by MRI or cause MRI magnetic artefacts. While these polymers do not undergo corrosion in the traditional sense described for metals, there are however concerns about possible leakage of their original components (monomers and so on). Carbon-reinforced PEEK offers a higher degree of tensile strength; however, this may cause problems due to possible release of carbon microfibers after implant breakage, fretting, and wear under dynamic load, which can cause a significant tissue reaction.

Conclusion

The use of both stainless steel and titanium and its alloys is well established in trauma surgery, each have advantages and disadvantages. Other materials have a more limited application, although there is considerable ongoing research to find alternatives to those used today.

1.5.1.2 Further reading

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1.5.2 Care and storage of implants   Judith Roberson

Operating room personnel require knowledge and skills relating to the principles and practices of the care, handling, and storage of sterile and nonsterile implants to achieve the best surgical outcome for the patient. The following recommendations should be used as a guide. Manuals regarding policy and procedures, and standard practice requirements relating to specific countries or health care facilities should always be adhered to. Consulting the relevant company's manual for information on storage and handling of any implant is also recommended.

The principle for storage of sterile items is the maintenance of sterility until items are selected and opened for use. Therefore, implants should be stored and handled in a manner that ensures prevention of contamination or damage from any source.

1.5.2.1 Storage environment

As with all sterile stock, implants must be stored in a specified area free from dust and external influences, such as insects and vermin. The routine cleaning of these areas should be established and documented. To facilitate cleaning and help prevent restricted air flows and inadvertent contamination, all sterile items should be stored at least 250 mm above floor level and at least 440 mm from the ceiling.

Shelving constructed of stainless steel, chromium-plated, or plastic-coated mesh is ideal, as lint and dust is less inclined to collect on them. Storage containers should meet the same requirements as shelving to be easily washed and dried. Surfaces such as chipboard, concrete, or other porous materials are unsuitable for storage of sterile items. All sterile stock must be removed from any large outer cardboard boxes or packaging before being stored in the sterile area (Fig 1.5-5).

Fig 1.5-5   Storage of sterile stock.

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

Ultraviolet light and heat cause degradation of packaging materials and contents of packs over time, resulting in unsterile, unusable stock. Sterile items, therefore, need to be protected from direct sunlight and other sources of ultraviolet light and heat generated by artificial lighting. The environment should also be cool and dry, as a high relative humidity may cause sterile items to become moist leading to the possibility of contamination.

Staff movements within the sterile storage area should be minimized to prevent the generation of airborne contaminants and to minimize inappropriate handling of sterile items.

1.5.2.2 Principles of care and handling of implants

Sterile items which have failed to cool within 2 hours of sterilization should not be enclosed in plastic dust covers for storage. This practice eliminates the risk of entrapment of contaminates.

Through the rotation of stock, sterile items should be managed with due consideration to the date of sterilization or manufacture. Older stock should be stored in such a manner that it is used before new stock; ie, first-in first-out principle. When ORP are responsible for the restocking of implants before resterilization of instrument sets containing implants, they need to pay particular attention to the rotation of implants. Setting up a routine for staff to follow to encourage rotation of implants is mandatory. In any situation when there is the slightest possibility that a sterile item might have become unsterile, it must be totally reprocessed.

"Standard policy/procedure" recommendations of the institution for packaging and wrapping materials should be followed to promote successful storage of sterile items (Fig 1.5-6). Package contents and events which occur during storage can also compromise the success of the storage; therefore, avoid rough handling of sterile items.

The distribution of sterile implants from various manufacturing companies or suppliers to operating rooms requires the implants to travel in transport vehicles, containers, or trolleys. These modes of transport should not be used for any other purpose other than for transport of sterile or clean products.

Fig 1.5-6a–c   Standard policy for packaging.
a   Unsterilized item.
b   Sterilized item.
c   Dust-covered sterilized item.

On arrival at the health care facility, handling of sterile items should be kept to a minimum to avoid inadvertent contamination through damage to the packaging. Avoid packing sterile implants too tightly into the storage containers and do not wrap them with elastic bands as the packaging may be compromised.

Each health care facility should develop a policy/procedure for checking borrowed sets to ensure that the correct surgical implants and instruments delivered by the lending company are available for a given procedure.

Nonsterile implants for orthopaedic procedures, eg, screws, plates, wires, and washers associated with trauma, craniomaxillofacial, and spinal procedures are supplied by manufacturers for the restocking of implant sets before sterilization. These items should be accompanied by instructions on processing and sterilizing. Although these items are intended to be used once, unused implants are designed and manufactured to undergo resterilization.

Once a sterilized set of implants is opened in the operating room, the unused implants in the set are regarded as opened but unused medical devices. Subsequent sterilization of unused implants may be undertaken. However, any item inserted into the patient during a procedure, even if it is subsequently removed, is considered as used and cannot be resterilized for further use. Although it may appear undamaged, previous stresses could create imperfections that may lead to mechanical failure.

Implants which are provided sterile by the manufacturer must always be stored unopened in their respective protective containers. Packages should always be inspected for damage without compromising the sterility. If the packaging is soiled, opened or damaged, sterility cannot be assured. Such items should be returned to the supplier for replacement or refund.

Implants are usually labeled as being for single use only, and cannot be resterilized if they are opened and then found to be unsuitable, even if they have not been inserted into a patient.

1.5.2.3 Checking and ensuring validity of sterile implants

To ensure that sterilized implants selected for surgery are in optimal sterile condition, the following checks must be undertaken:
- Integrity of packaging
- Sterilization and expiry date
- Type of sterilization process
- Serial or lot number corresponding to the company's checklist
- If implants are sterilized on site the same checks are performed.

Further checks to be done are:
- Confirmation of validation of the sterilization process before being cleared for use
- Batch control (sterilizer number/code)
- Cycle or load and chemical/biological indicators
- Wet items or items that have come into contact with wet surfaces have to be rejected
- Lack of sterilizing indicator means item is not sterile and requires reprocessing

Commercially prepared items are produced by organizations which are required to be licensed and registered by official legislation pertaining to the country concerned. Symbols appearing on implant packaging of the product indicate compliance with essential requirements related to safety, health, and environment necessary for consumer protection as required by law.

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

1.5.2.4   Intraoperative handling and tracking

Intraoperatively and before opening of sterile implants, the surgeon states the size and side of the required item. The circulating nurse selects the requested item/implant and confirms it with the instrument nurse and surgeon, both verbally and visually. The circulating nurse delivers the item/implant to the instrument nurse and sterile field using an aseptic technique. Handling of any implant should be kept to a minimum, avoiding unnecessary contact with other surfaces or grossly contaminated gloves. Implant details are recorded in the patient's medical record and elsewhere as required by institution protocol. This implant history is also of benefit when the patient requires removal of implants.

Familiarity with and attention to the surgical technique is recommended for the insertion of any implant and is imperative for satisfactory results. Only the correct and appropriate instruments should be used to insert implants. When necessary, contouring and bending of implants should be kept to a minimum, as it may reduce service life of the item and lead to its immediate or eventual failure under load stress.

The practice of implant tracking is increasingly common among health care facilities worldwide and is becoming standard practice. The principle is to efficiently trace or link equipment, instruments, and implants to any particular patient so that they can be traced in the event of a breach in the manufacturing or sterilizing process. It is essential for the health care facility to keep full and detailed records of all devices or implants used for each individual patient.

ORP are the patient's advocate, so they must pay special attention to the care, handling, and storage of implants which is extremely important for the positive surgical outcome of every patient.

1.5.2.5   Further reading

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1.5.3   Damaged and broken implants   Nicola Kildea, Anna Wilkins

The task of any fracture fixation device is to provide enough stability at a fracture site to restore function and anatomical alignment, while optimizing conditions for fracture union. To achieve optimal performance from a fixation device, the implant used needs to be in perfect condition. It is therefore important that before use, resterilized implants are carefully checked for deformation, microcracks, and surface defects (such as scratches). Instruments used for implantation must also be examined, as worn or damaged instruments may be a cause of implant damage, eg, a damaged recess of a screw head due to a worn screwdriver tip (Fig 1.5-7).

A damaged implant has the potential to fail more readily than an undamaged device, and failure jeopardizes successful fracture healing. For example, microcracks in a screw can lead to weakening which increases the likelihood of breakage after implantation. Implant failure frequently results in fixation failure. Even if this is not the case exposed broken implant edges can lead to

Fig 1.5-7   Checking of instruments.

soft-tissue irritation and are more likely to bring about the need for metalwork removal, which in the case of broken screws can be technically challenging.

The accidental damaging of an implant during surgery may also occur; for example, the hexagonal head of a screw may become damaged by over tightening with a screwdriver. Again, this makes subsequent screw removal difficult and can lead to increased surgery time. For other devices, such as plates, too much bending, particularly if it is bent repeatedly, will weaken the plate and may lead to early failure. Bending LCP or other locking plates too much may also slightly deform the thread-bearing part of the combination hole, rendering it incapable of holding a locking head screw.

1.5.3.1   Implant removal
Preoperative information and planning are the key to successful implant removal (see chapter 2.14).

If any implant (ie, intact, broken, or damaged) has to be removed the correct equipment must be available. The original implantation set may be sufficient but special removal sets frequently need to be ordered. If the implant has been inserted in another hospital the exact type of implant must be identified and the correct removal instruments obtained. The patient's latest x-ray is essential to identify exactly what had been inserted or how many broken implant pieces are present. The original operation records will facilitate gathering details of inserted implants.

At surgery ORP must count all removed components and confirm their number with the surgeon. A final postoperative x-ray will document that nothing foreign has been left in the patient.

Tips for handling difficult removal scenarios are in chapter 2.14 and further details are presented in the *AO Manual of Fracture Management*.

1.5.3.2   Troubleshooting
Implants required for each patient together with all instruments for insertion and removal should be checked before he/she is anesthetized. Note, frequently used implants should be stocked; thus, if an implant is found to be damaged immediately before insertion, a spare one is available. Delivery times by the supplier should also be considered. If these are slow or unreliable, it may be necessary to have a larger inventory to avoid unavailability.

Borrowing implants from other local hospitals is not ideal but may be the solution in an emergency.

If an operation is specialized or complex, planning may identify the need for specialized implants to be ordered before planned surgery. Specific patient groups, particularly those from Asia, may require smaller size implants; for example, smaller diameter intramedullary nails.

Authors   Nicola Kildea, Jessica Hayes, Judith Roberson, Anna Wilkins

Surgeons and ORP should be aware of all implant systems available in their institution. Preoperative planning and good communication within the whole surgical team is essential to ensure correct implants and instrumentation are at hand before any procedure begins. A sound knowledge of all available implants and the associated insertion and removal procedures will avoid disruption during an operation. Instruction manuals of implants and operating techniques should be kept for easy reference.

Acknowledgment

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

1.6   Equipment

1.6.1   Operating room table   Sari Cohen

1.6.1.1   Introduction

Proper patient positioning is essential to allow surgery to proceed in a correct, safe, and successful manner. The goals of correct patient positioning include providing optimum exposure and access to the surgical site, maintaining body alignment, supporting cardiovascular and respiratory function, protecting neuromuscular and skin integrity, and allowing the anesthetist access to the airway, intravenous sites, and anesthetic support devices. Insufficient care in transferring and positioning a patient can have a damaging effect on them.

The operating room personnel (ORP) must be knowledgeable, experienced, and trained in positioning the patient for surgery. Correct positioning requires understanding and awareness of the physiological effects and the implications and risks of positioning in relation to the patient's general and medical condition.

Planning is necessary to ensure correct and safe positioning. Preoperative assessment includes both patient and intraoperative factors. Patient factors include age, height, weight, skin condition, nutrition status, and physical/mobility limits. Intraoperative factors include type of anesthesia, length of surgery, position required for the operation, and the need for intraoperative imaging.

Teamwork is essential for safe and appropriate patient positioning. Although the surgeon has the final responsibility for the safety of the patient, successful patient positioning can only be achieved by cooperation and coordination of the whole surgical team. ORPs have a leading role in this aspect of patient care. Adequate number of personnel must be available to position the patient on the operating table (OT). Consideration must be given to the type of OT required (standard table, radiolucent table, fracture table, or table for spine surgery). The table must be checked to ensure that it is in good working order, and that the appropriate padding, positioning devices, and attachments are available. In the operating room, it should be positioned so as to allow access for additional equipment (eg, an image intensifier).

1.6.1.2   Operating tables

Of all surgical specialities orthopaedics is the one with the greatest variety of patient positioning. Operating tables are designed to support the patient in these positions. Because the requirements are so varied specialized orthopaedic tables have been designed.

General OTs are composed of a platform divided into major sections: the head, torso, and leg (Fig 1.6-1). Each has a corresponding removable mattress pad. The area between each section is called a break; each section can be angled relatively to its adjacent section—this is called breaking the table. The torso section is attached to the base of the OT.
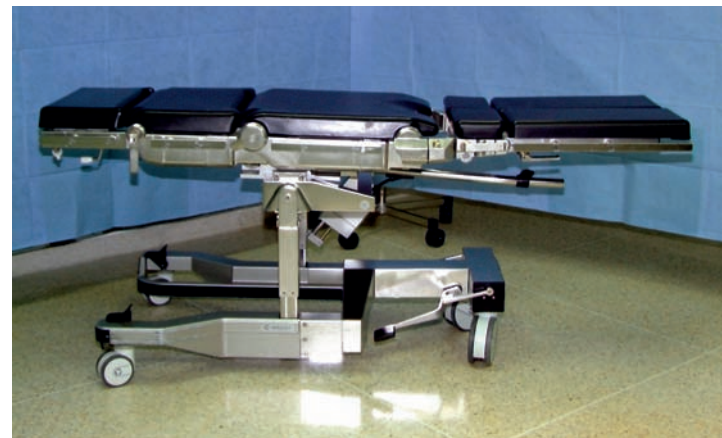
Fig 1.6-1   Mobile operating table.

Along the edges of each section of a general table run flat metal side rails with a gap at each break. These allow attachment of accessories, such as arm boards, hand tables, and overhead arm supports to be fitted to the table, either directly or using clamps that are fastened onto the rails.

The table height can be raised or lowered, and the table top tilted laterally or tipped head down (Trendelenburg position) or head up positions. Modern OTs are generally electrically or battery operated with a manual mechanical backup, although older manual tables are used in many countries. They have roller wheels which allow them to be moved and a brake that locks them in place. In newer models, the entire table platform is radiopaque to accommodate the use of intraoperative fluoroscopy.

Most types of surgery can be performed on an unmodified standard OT, including lower limb surgery. The attachment of a hand table facilitates hand surgery.

Shoulder surgery can be performed by applying a back plate attachment and head support. The knee-chest position for lumbar laminectomy or discectomy can be achieved by attaching a vertical extension platform onto the end of the foot section of the standard OT. An extension may also be needed for tall patients.

Special orthopaedic OTs are designed for specific operations. The fracture table allows access for an image intensifier. AP and lateral views of the proximal femur can be obtained when performing hip fracture surgery and closed femoral nailing (Fig 1.6-2). The unaffected leg is raised and supported in a padded leg rest, while

Fig 1.6-2a–b
a   Image intensifier access for AP view.
b   Image intensifier access for lateral view.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

traction can be applied to the affected leg either indirectly by placing it in a boot, or for a stronger pull by placing a Steinmann pin through the distal femur.

Modular base table technology comprises a permanent table base which accepts standard, orthopaedic trauma, Jackson spinal, maximum access, and imaging table tops. The tops can be switched depending on the type of surgery. Modular base table tops are generally made of a radiolucent composite material that allows unrestricted image intensifier use.

1.6.1.3   Parts and accessories
Each OT is designed with parts and accessory devices that can accommodate most surgical positioning needs (Fig 1.6-3).

These accessories are used to achieve the optimal, safe, and adequate positioning of the patient for surgery. Accessories required depend on the OT type, the preference of the surgeon, and the patient's weight and size. They include padding and pressure-relieving devices, such as durable mattress and gel products. These are used as an overlay to the mattresses, and positioning devices are used to fix the patient in a stable position. They minimalize pressure effects on soft tissues by distributing pressure evenly and thus decrease the potential for injury (Fig 1.6-4).

Accessories for OTs from different manufacturers are often not compatible with each other. This must be considered when scheduling surgery if the OR has tables manufactured by different companies.

Fig 1.6-3   Accessory devices for OR tables.

Fig 1.6-4   Pressure-relieving devices.

When positioning a patient note that different individuals have different anatomical and physical limitations. This particularly applies to the elderly in whom the joints may be stiffer and the bones osteoporotic. Rough handling of such patients when administering anesthesia or during positioning can lead to fractures or joint dislocations. All ORP must be familiar with the proper function and use of the positioning equipment and accessories required to maintain the safety of each patient.

Selection criteria for positioning devices and accessories are based on:

- Position needed for surgery
- Availability of appropriate sizes and shapes
- Durability of material and design
- Ability to maintain normal capillary interface pressure
- Resistance to moisture and microorganisms
- Radiolucency
- Fire resistance
- Water resistance
- Nonallergenic to the patient
- Ease of use
- Ease of cleaning/disinfection, if not disposable
- Ease of storage, handling, and replacement
- Cost-effectiveness

Conclusion

Every orthopaedic OT should be of appropriate design and have suitable positioning devices and accessories available. These are used for positioning the patient for surgery, allowing maximum safe anatomical exposure of the surgical site. Equipment function should be verified before every use and must be maintained and used according to the manufacturer's instructions.

Before a patient enters the OR the position required must be known and the proper OT prepared and be in good working order. Any positioning accessories or table attachments that might be needed must be available.

Special orthopaedic OT components are often used several times daily. All accessories belonging to the OT need to be stored carefully to prevent any damage or loss. This is best done in a designated area close to the orthopaedic rooms.

Properly functioning equipment, used correctly, will achieve safe positioning of the patient and good exposure of the surgical site.

1.6.1.4 Further reading

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Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

1.6.2   Image intensifier   Poh Yan Lim, Merng Koon Wong

The discovery of x-rays had a profound impact on the diagnosis and management of fractures. The subsequent development, introduction, and improvement of image intensifier technology has had an equally profound impact on trauma surgery as it allows immediate verification of fracture reduction and accurate positioning of orthopaedic implants on bone. However, as with any medical equipment, the benefits, risks, and limitations must be thoroughly weighed and balanced.

Ionizing radiation

Ionizing radiation is electromagnetic or particulate radiation capable of producing ions, directly or indirectly, in its passage through tissue. It alters atoms by removing one or more electrons, leaving positively charged particles known as free radicals. These free radicals may cause changes in DNA causing it to mutate and this can set off the development of malignancies. The amount of damage done by ionizing radiation depends on the dose received.

Alpha and beta particles, gamma rays, and x-rays are all forms of ionizing radiation. X-rays and gamma rays are forms of short wavelength electromagnetic radiation.

Diagnostic imaging

There are three primary components in an x-ray imaging system, ie, an x-ray source, the object to be x-rayed, and a system for detecting and displaying the resultant image.

The x-ray source produces x-rays using high-voltage electricity in a vacuum. The operator is able to focus the beam in a process called collimation. The smaller the area focused, the sharper the x-ray image and the smaller the dose. Collimation is exactly the same process as the setting of the aperture on a conventional camera (Fig 1.6-5). The operator is also able to select predetermined settings of an x-ray exposure dose and to initiate the exposure.

The x-rays produced penetrate the body which absorbs, refracts, or reflects the x-ray beam energy depending on the tissue. Bone

Open beam

More tissue irradiated

More image degradation

a

Collimated beam

Less tissue irradiated

Less image irradiated

b
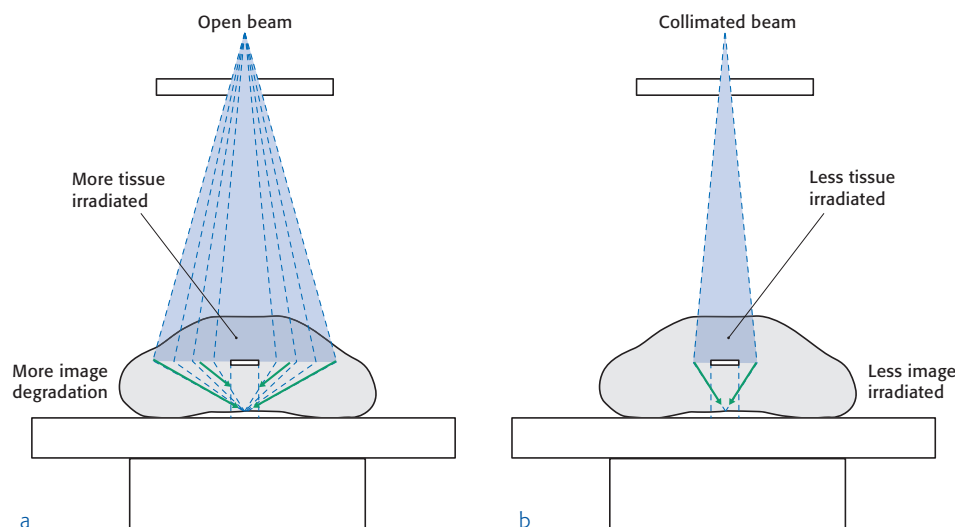
Fig 1.6-5a–b   Collimation.

will reflect and absorb most x-rays while soft tissue will allow penetration. It is this differential of x-ray penetration which results in being able to visualize human bone and joint anatomy using x-rays.

When x-rays reach the target-imaging plate and are absorbed, they cause certain substances on the imaging plate to fluoresce; thus emitting photons of lower energy. This is how x-rays can produce an image on a photosensitive film which can then be made visible by developing it. Alternatively, an x-ray sensitive cartridge is used which is developed to produce an electronic version of the image which is downloaded onto a computer network. An image intensifier captures this fluorescence in real time, transmitting it to a screen. X-ray dose is measured using the "Gray scale" (Gy), an international unit of absorbed dose.

The image intensifier has three main parts—the x-ray tube, the image intensifier collector, and the display screen (Fig 1.6-6). Note that x-rays come from the tube and are fired toward the collector.

For good-quality images the beam of the x-ray should travel perpendicular to the limb/bone with the image intensifier receptor as close to the patient as possible. The source-to-patient distance must be at least 38 cm for image-intensified fluoroscopic units.

Hazards of radiation exposure

Everyone is subjected to background radiation and most is derived from cosmic rays. Some comes from the earth itself and small amounts from medical and other artificial sources. These background levels are always present and pose little hazard.

2. Image intensifier collector

3. Display screen
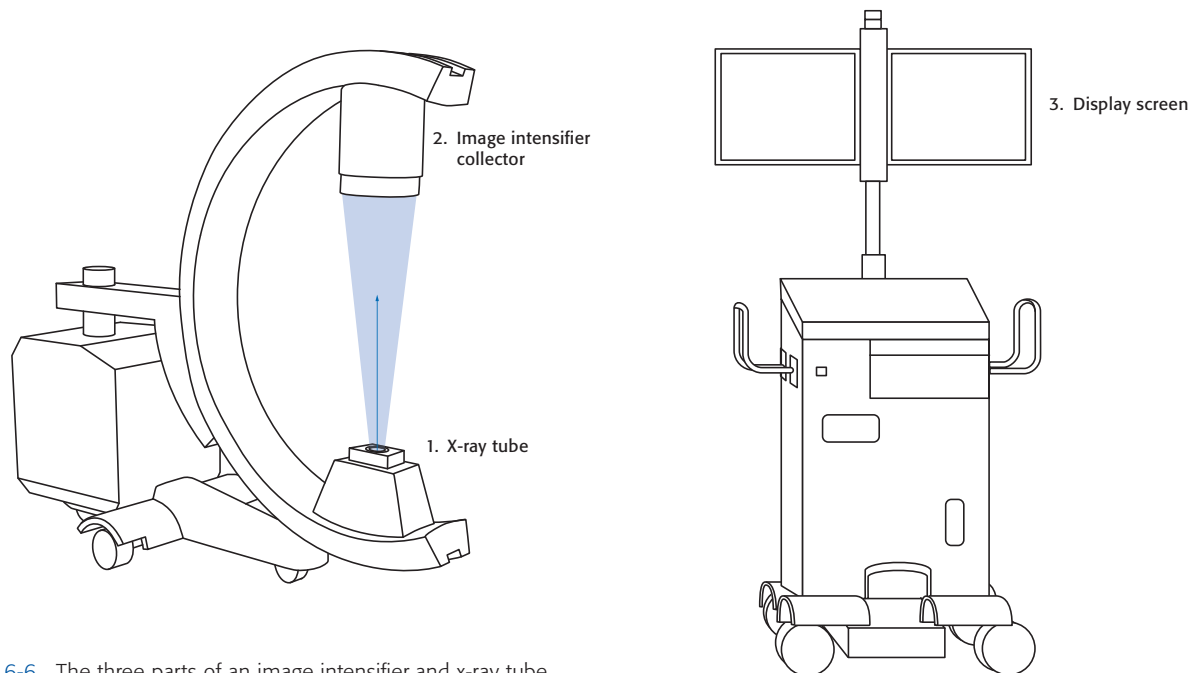
1. X-ray tube

Fig 1.6-6   The three parts of an image intensifier and x-ray tube.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

Radiation sources are found in a wide range of occupational settings. If radiation is not properly controlled, it can be potentially hazardous to the workers' health and can lead to development of cancer in sensitive organs, particularly in the thyroid and in bone marrow. The developing fetus is particularly at risk and exposure should be minimized in pregnancy. Exposure to x-rays is cumulative; thus, long periods between doses do not lessen the risks.

1.6.2.1   Radiation safety

Although modern x-rays have minimal radiation effects on the patient, frequent, prolonged, and repetitive use of intraoperative image intensification have greatly increased the risk of significant radiation exposure to the surgical teams. It is the responsibility of every surgeon to be familiar with the image intensifier and to know how to minimize radiation exposure to himself/herself, the patient, and other members of the surgical team. Image intensifier machines which are able to store and then show the images taken have the effect of greatly reducing the radiation dose to which the patient and the surgical teams are exposed.

The system of radiation protection recommended by the International Commission on Radiological Protection (ICRP) in Publication 60 is based on three major principles:

Justification of practice

A practice which involves exposures or potential exposures should only be adopted if it is likely to produce sufficient benefit to the individual or society to outweigh the detriment or harm to health.

Optimization of protection—ALARA principle

Individual doses, the number of people exposed, and the likelihood and magnitude of potential exposures should be kept As Low As Reasonably Achievable (ALARA), economic and social factors being taken into consideration.

Individual dose and risk limits

The ICRP recommends that exposure of individuals should be subjected to dose limits, aimed at ensuring that no individual is exposed to unacceptable risks. Certain harmful effects of radiation, such as cataract formation, are dependent on dose. Patients and staff exposed to radiation below a certain dose (threshold dose) are not at risk of developing this complication. These effects are called deterministic. Other harmful effects of radiation do not have a threshold dose. The adverse effects which can include cancers are related to the absorbed dose but any exposure can potentially be harmful. These effects are called stochastic. The aim is to prevent any deterministic effects and minimizing the chance of stochastic effects (Tab 1.6-1).

The most important principle of radiation protection is to keep all doses As Low As Reasonably Achievable while still allowing the beneficial use of ionizing radiation. The recommendations of the ICRP can be applied at several levels to control the hazards from radiation.

Application	Dose limit occupational	Correct patient
Effective dose	20 mSv per year, averaged over defined periods of 5 years	1 mSv in a year
Annual equivalent dose in:		
lens of the eye	150 mSv	15 mSv
skin	500 mSv	50 mSv
hands and feet	500 mSv	–

Tab 1.6-1   Recommended dose limits.

Regulatory requirements

The ICRP and many national regulatory agencies worldwide adopt a conservative stance with regard to radiation protection in radiology and medicine. The reason is that evidence surrounding low-dose radiation and its resulting risks is inconclusive.

The formulation and implementation of regulations and legislation varies from country to country. Regulations provide a link between the ICRP recommendations and their implementation in the workplace. The regulations define a satisfactory standard of protection and apply to all justified practices.

Management requirements

Management has the important role of implementing system safeguards for quality control and safety. It should also take potential exposures into account and institute risk analysis to identify possible causes of incidents and limit the probability and effect of such incidents. Regular quality control tests should be done to detect deterioration in equipment performance to minimize undue patient and staff radiation exposure.

One of the main responsibilities of this management is to encourage a good attitude to safety and recognition that safety is a personal responsibility. In addition, the management should optimize protection by clearly defining responsibilities and providing clear and simple operating instructions.

Monitoring

Absorbed dose by staff members needs to be monitored by means of thermoluminescent dosimeters (TLDs) and personal pocket dosimeters. TLDs are able to record total exposure, while pocket dosimeters are used to immediately determine radiation exposure. They are to be worn at the waist level and are the most accurate form of monitoring workers' exposure to radiation.

Foundation for a safety program

Absorbed dose is related to duration, distance, and shielding. The three major techniques to maintain the ALARA principles are reducing duration of exposure, increasing the distance to the source of exposure, and shielding.

Duration

Minimizing the duration of exposure directly reduces the radiation dose:
- Keep beam-on time to a minimum
- Inform the radiographer where the C-arm is positioned
- Perform a trial screening in the planned projections after positioning of patient
- Take only the minimum number of images required
- Rely on stored images without the need for reexposure
- Minimize use of magnification (source close to limb)
- Collimate the image whenever possible
- Use single-pulsed mode image intensification and pulsed-screening mode, instead of continuous image intensification. Studies suggest that screening time is controlled predominantly by the surgeon
- Controlling the dose received by the patient will helps in turn control the dose for the staff

Distance

The further you are from an x-ray source, the less radiation you will receive. The inverse square law states that the dose of radiation received is inversely proportional to the square of the distance from the x-ray source. Therefore, increasing the distance between you and the source of radiation a little bit will significantly reduce the dose of radiation received. Doubling the distance reduces the radiation to a quarter.

Shielding

Exposure to radiation is reduced if dense-absorbing material such as lead and concrete are used to surround x-ray units. The doors and walls of operating rooms designated for image intensification

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

should be shielded with lead and made of reinforced concrete, respectively (Fig 1.6-7).

Protective equipment for staff (Fig 1.6-8) and patients must be provided and used. The following are recommended:

- Gowns/aprons/skirt/vest with 0.5 mm lead equivalent for surgical teams
- Neck shields to protect the thyroid
- Lead glasses decrease exposures of the eyes, 0.15 mm lead equivalent goggles provide 70% attenuation beam energies
- Gonad shielding of at least 0.25 mm lead equivalence must be

used on patients of reproductive age, if the gonads are in the primary beam and the shielding does not interfere with the diagnostic procedure
- Lead screens provide additional protection of OR personnel who do not wear lead protection. Viewing glass materials must have the same lead equivalence as the shield
- Scattered radiation under the table must be attenuated by at least 0.25 mm lead equivalence shielding
- Walls, ceiling, doors, and floor areas of rooms housing diagnostic units must be provided with sufficient protective shielding (lead or lead equivalent materials)

Fig 1.6-7   Leaded door.
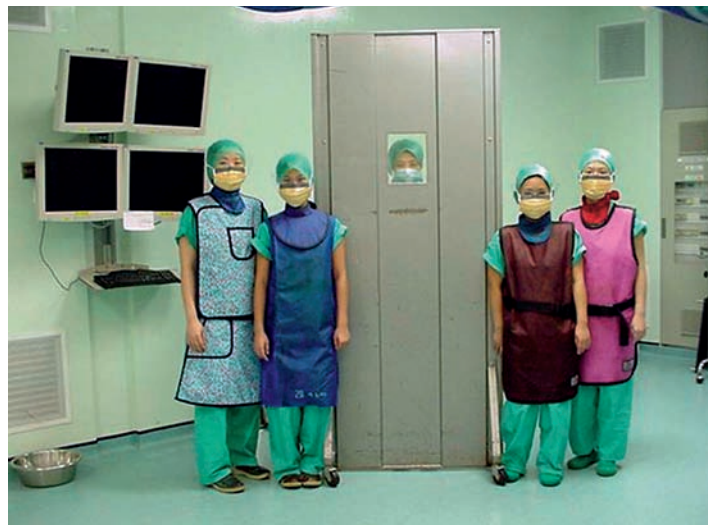
Fig 1.6-8   Proper protective equipment and lead screen for OR staff.

Note that the reduction in radiation dose provided by a lead apron depends on its physical condition, how it is worn, its lead equivalence, and the strength of the x-ray beam. Lead aprons cover about 75–80% of a person's active bone marrow. Crumpling of the lead apron will break the integrity of the lead-fiber shielding, reducing its effectiveness. Therefore, lead aprons should be properly hung up after use and not folded in any manner (Fig 1.6-9).

Scatter

Not all x-rays pass through the object on which they are focused. Some are also reflected and refracted as they penetrate through the object resulting in scatter. Members of the surgical team standing close to the patient are at particular risk of exposure from scatter. It is therefore important to understand how this can be minimized.

The maximum scatter comes from the side of the patient that is closest to the x-ray tube (Fig 1.6-10). The side of the patient closest to the image intensifier gives off less scatter because the direct beam and scattered radiation are reduced as they pass through the patient due to absorption.

Fig 1.6-9a–b
a   Proper care of aprons.
b   Improper care of aprons.
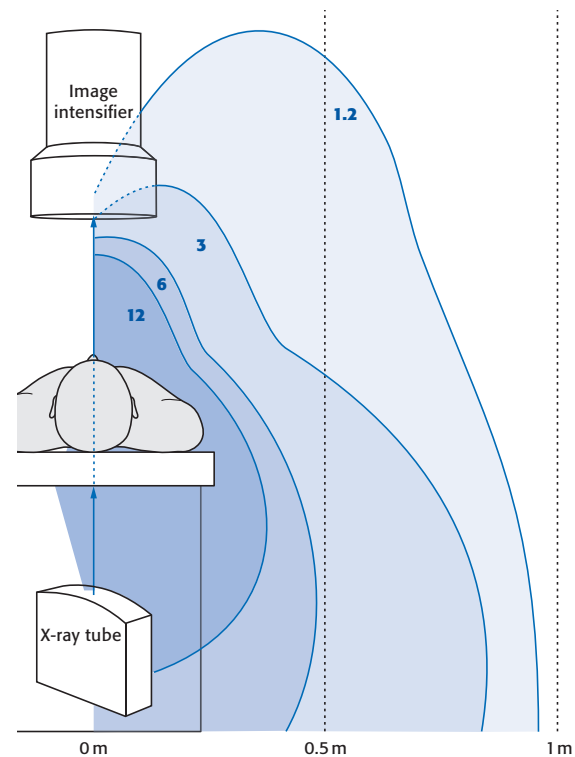
Fig 1.6-10   Scatter dose diminishes with distance.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

Therefore, during image intensification, whenever possible:
- The x-ray beam should be aimed in such a way that the scatter is going toward the floor and not into the surgical team. In practice this means placing the x-ray tube under the patient.
- The image intensifier receptor should be kept as close as possible to the patient (Fig 1.6-11). This not only reduces scatter but also improves image quality and reduces radiation dose.
- Since the amount of scatter produced increases with the size of the area irradiated, it is good practice to restrict the field size to the area receiving imaging.

- Staff exposure can be limited by keeping as far from the beam as physically possible when an image is being obtained.
- In the lateral projection, the source (ie, x-ray tube) is usually at the surgeon's side; the surgical team should stand further away from the source, and no one should stand directly behind the image intensifier receptor itself as x-rays are aimed directly at it.
- Surgeons and assistants who must face the operation site during the use of the image intensifier should avoid being positioned directly in the beam (Fig 1.6-12).
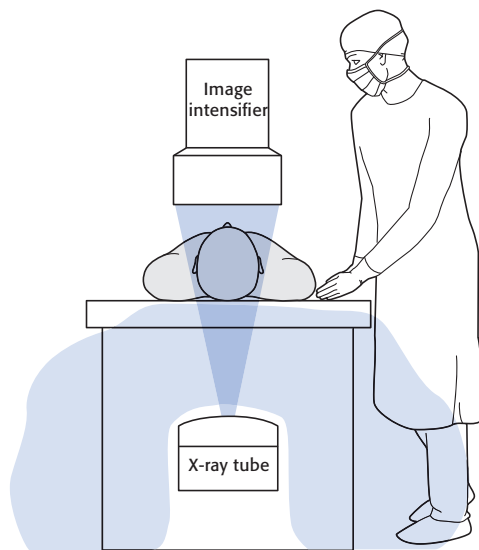
Fig 1.6-11   Image intensifier positioned as close as possible to the patient.
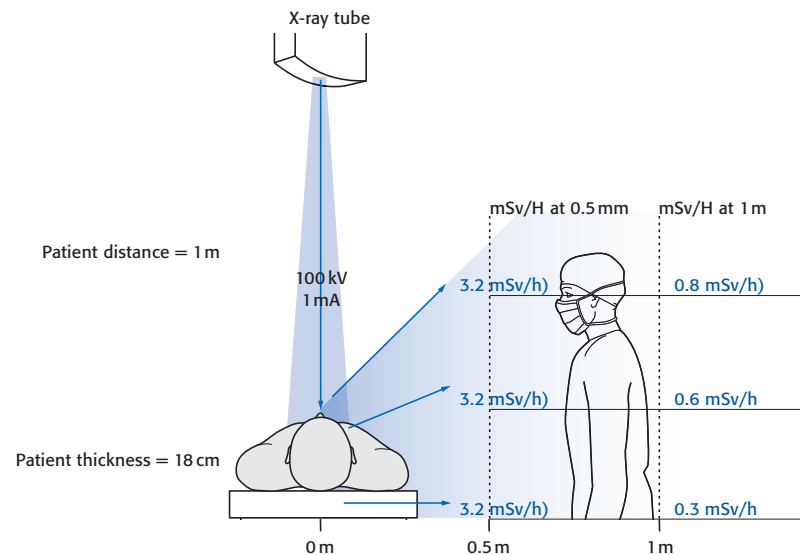
Fig 1.6-12   Note the effectiveness of distance relating to the received scattered radiation dose.

1.6.2.2 Documentation

Every hospital must have a radiation safety protocol as an integral part of the occupational health and safety program. Although regulations and practice varies in different parts of the world, the following principles should apply:

- Written policies and procedures address compliance with applicable standards, laws, and regulations
- Attendance at the radiation safety awareness program for hospital staff is mandatory
- All employees who are exposed to radiation are registered and are assigned personal thermoluminescent dosimeter (TLDs) to monitor their radiation exposure:
  - The regulatory authority will issue a new TLD every 2 months and report the result
  - TLDs have to be worn at the waist level, beneath a lead apron
- Handling of lead aprons:
  - Lead aprons are tagged with an ID, and are inspected annually
  - Reports are to be filed by the user department
  - Proper metal racks constructed to hang the lead aprons must be used when aprons are not in use
- Posting and labeling: All operating rooms with x-ray/image intensifier machines shall be clearly and visibly labeled to caution individuals that such machines produce radiation when operated
- Radiation safety inspection checklist to aid in auditing/inspecting radiation areas should be created
- Radiation safety and radioactive waste disposal manuals made available in the hospital intranet
- All x-ray machines come with a "use log" requiring the following information each time the machine is used:
  - Date of use
  - Name of the operator
  - Description of use
  - Beam voltage, beam current
  - Time beam turned on and off
  - Comments concerning operation abnormalities, repairs, and so on

Conclusion

Increased use of x-ray and image intensifiers is inevitable in the operating room making radiation in the operating environment unavoidable. The risk to patients and staff can be easily reduced by adhering to the central principles of the ICRP recommendations: instill awareness among the healthcare workers, understand risks of working in a controlled area, understand individual responsibilities, and practice correct behavior; last but not least, understand the radiation protection measures available in your work setting.

1.6.2.3 Further reading

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Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

1.6.3   Pneumatic tourniquet   Poh Yan Lim, Merng Koon Wong

The inflatable (pneumatic) tourniquet was developed by Harvey Cushing in 1904. To constrict the blood vessels of an extremity, compressed gas was introduced into a cylindrical bladder. This device had two advantages over the Esmarch tourniquet, as it was quicker to put on and take off and there was a significantly lower incidence of nerve paralysis.

The use of two tourniquets for administering segmental anesthesia was introduced by August Bier in 1908. In this two-tourniquet procedure, circulation is isolated in a portion of the extremity and a local anesthestic is infused intravenously. This intravenous regional anesthesia (IVRA) is commonly called a Bier block (see chapter 1.1).

In the early 1980s, electronic tourniquet systems (also called computerized or microprocessor-controlled tourniquets) were introduced by James McEwen. These automatic tourniquets are safer and more reliable than previous mechanical pressure-regulated systems.

A tourniquet can be defined as a constricting or compressing device used to control venous and arterial circulation to an extremity for a given period. Pressure is applied circumferentially on the skin and underlying tissues of a limb. This pressure is transferred to the walls of blood vessels, causing them to become temporarily occluded. In surgical settings, a tourniquet is used following exsanguination to produce a near bloodless operative field.

1.6.3.1   Types of tourniquets

Two types of tourniquets are available:

- Noninflatable (nonpneumatic) tourniquets made of rubber or elastic cloth. Their surgical use is now limited. For prehospital care of a patient with trauma to an extremity, a nonpneumatic tourniquet may be used as a last resort to control hemorrhage.
- Pneumatic tourniquets use a gas-inflated cuff to constrict the blood flow. This method is no different from the blood pressure-measuring cuffs. However, pneumatic tourniquets used in operating rooms have cuffs whose pressure is controlled electronically. All cuffs leak slightly and small amounts of gas have to be pumped into the system to maintain the cuff pressure during an operation. The use of an electronically controlled cuff which does this automatically allows precise control of cuff pressure (Fig 1.6-13).
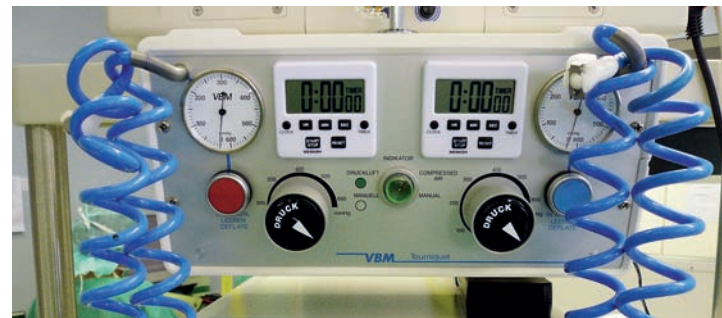
Fig 1.6-13   Tourniquet monitor for two limbs.

Contraindications

The risks of using a tourniquet for temporary vascular occlusion during a surgical procedure must be assessed before application. Tourniquet use on limbs with compromised vascularity should be avoided.

Situations in which tourniquet use is contraindicated include:

- Infection
- Open fractures
- Intramedullary reaming of tibia
- Venous thromboembolism
- Tumor distal to the tourniquet
- Posttraumatic hand reconstruction of long duration
- Severe crushing injuries
- Compromised vascular circulation, eg, peripheral artery disease
- Extremities used for dialysis
- Diabetes mellitus
- Sickle cell anemia
- Skin grafts where all bleeding points must be readily identified

There is some evidence that the use of a tourniquet can delay postoperative healing. This is a controversial subject and the surgical team has to consider the benefits of a bloodless field and reduced surgical time against any perceived risk.

1.6.3.2   Precautions for use

- The tourniquet system must be kept well calibrated and functional. Accessories should be checked regularly for leaks and other defects before each use.
- Careful and complete exsanguination prolongs pain-free tourniquet time and improves the quality of IVRA.
- Exsanguination using an elastic bandage helps achieve a bloodless field but is contraindicated in the presence of infection, fractures, and malignant tumors. Elevating the limb for at least 30 seconds is sufficient to allow venous blood to exit the extremity.

- The tourniquet cuff must be applied in the correct position on the limb:
  - For the upper arm and thigh, the optimal positions are the proximal third of the extremity.
  - For the lower leg, it should be placed over the calf at its point of greatest circumference.
- A tourniquet must never be placed over the area of the common peroneal nerve in the proximal calf or directly over the knee or ankle joint. A cuff that has been inflated should not be adjusted by rotating it because this produces shearing forces which may damage the underlying tissue.
- Prolonged ischemia may lead to temporary or permanent damage to tissues, blood vessels, and nerves. Tourniquet paralysis may result from excessive pressure to a peripheral nerve. Insufficient pressure in the cuff may result in passive congestion of the limb and precipitate a compartment syndrome, with possible irreversible functional loss. Prolonged tourniquet time can also produce changes in the coagulability of the blood with increased clotting time.
- Inflation should be performed rapidly to occlude both arteries and veins simultaneously so as to avoid venous congestion.
- In case of failure to achieve a bloodless field, the tourniquet-cuff pressure can be increased in advancements of 25 mm Hg until the operating area is sufficiently bloodless. It is sometimes better to deflate the cuff and reexsanguinate the limb before the tourniquet is inflated again. Reinflation of an over blood-filled venous system may lead to intravascular thrombosis.
- Personnel using tourniquets must be familiar with the inflation-deflation sequence when using a dual-cuff tourniquet for IVRA.
- The proper cuff size should be selected for each individual to allow for an overlap by the inflatable portion of the cuff by about 5–10 cm. Too much overlap may cause cuff rolling and telescoping, and may lead to undesired pressure distribution on the limb. Too short a cuff with too little overlap of the inflatable bladder portion produces uneven distribution of

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

pressure and may lead to loosening of the cuff or an inability to sustain occlusion.

- The skin under the tourniquet cuff must be protected by a soft padding, such as two layers of an elastic stockinette. A smooth, wrinkle-free application of the cuff helps prevent mechanical injury to the underlying tissues (Fig 1.6-14a–b). The deflated cuff and all underlying bandages should be completely emoved as soon as tourniquet pressure is released. Even the slightest impediment of venous return may lead to congestion and pooling of blood in the operative field.
- If skin preparations are used preoperatively, they should not be allowed to flow and collect under the cuff where they may

cause chemical burns. The use of an occlusive drape or protection with impermeable tape is recommended (Fig 1.6-14c).

- When the tourniquet cuff pressure is released, the wound should be protected from blood surging back into the limb by applying appropriate dressings and, if necessary, elevating the limb. Transient pain upon release of tourniquet pressure can be lessened by elevation of the limb. If full skin color does not return within 3–4 minutes after release of the tourniquet, the limb should be placed in a position slightly below body level.
- When IVRA is used, the tourniquet must remain inflated for at least 20 minutes from the time of injection (see chapter 1.1).
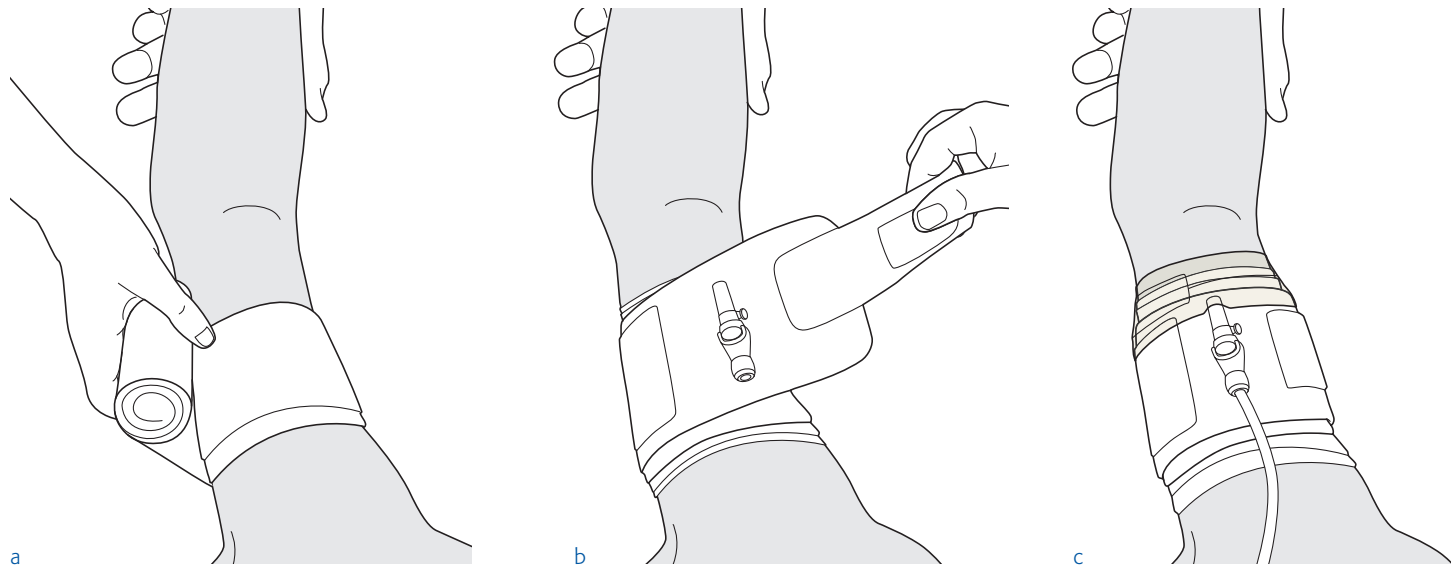
Fig 1.6-14a–c
a   Soft padding for skin protection.
b   A wrinkle-free application of tourniquet cuff.
c   Antifluid protection with impermeable tape.

Adverse effects

A dull-aching pain (tourniquet pain) may develop throughout the limb following the use of a tourniquet. Pathophysiological changes owing to pressure, hypoxia, hypercarbia, and acidosis of the tissues can occur and the frequency of complications increases significantly after about 1.5 hours of tourniquet use. Symptoms of tourniquet paralysis are motor paralysis and loss of the sense of touch, as well as pressure and proprioceptive responses.

Postoperative care and complications

After removal of the tourniquet the patient should be observed and monitored for at least 15 minutes to exclude risk of complications, which can include:

- Local injury to the skin, muscle, nerves, and vessels underneath the tourniquet
- Vascular damage, venous congestion, or emboli distal to the tourniquet site
- Hematoma and edema
- Compartment syndrome
- Pulmonary embolism

1.6.3.3 Tourniquet use

Single-cuff operation

The unit is connected to an electrical socket. The unit will execute a self-check diagnostic test when switched on:

- Do not apply a tourniquet if the skin is in poor condition or blistered.
- The minimum effective pressure should be used. The amount is determined by the preoperative systolic blood pressure and the maximum anticipated rise in systolic blood pressure during the procedure. Pressure needs to be higher in the leg than the arm and higher in fat limbs.
- A leak-free tourniquet cuff should be applied smoothly without wrinkles. The valve port and the connections should be placed so that the hose will not be kinked when the limb is positioned for surgery. The limb is then prepared and draped for surgery.

- The tourniquet time largely depends on the patient's anatomy, age, and absence of vascular disease. The surgeon will determine:
  - When the tourniquet is to be inflated
  - To what pressure
  - For how long
  - Whether to allow for intermittent aeration of tissues by deflating the cuff for 10–15 minutes
  - At what point during the operation the tourniquet should be released

It is generally agreed that for reasonably healthy adults tourniquet use is safe for about 1.5 hours, but 2 hours should not be exceeded without releasing the tourniquet to allow the underlying tissue to oxygenate. During this time the limb should be elevated about 60°, and steady pressure should be applied to the incision with sterile dressings:

- The cuff is inflated to the preset pressure and the inflation timer restarted.
- At the end of the procedure, the cuff is deflated.
- It is recommended that the tourniquet cuff and any underlying bandages are removed immediately after final deflation. The time of tourniquet cuff removal should be noted, and the circulation of the limb must be checked. The total tourniquet time must be recorded.

Dual-cuff operation

Operation of the unit is identical to single-cuff operation, except for the following:

- Both dual port cuffs are connected at the bottom of the unit
- Deflation of the second cuff is not possible while the first is inflating
- When inflating the second cuff with the other cuff already inflated, the unit will continuously check the original cuff to ensure that the pressure is within allowable limits. The unit will stop its inflation and maintain the original cuff to within 10 mm Hg of the set point before returning to the inflating cuff. This ensures that at least one cuff maintains occlusion at all times.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

Cuff shape

Standard rectangular (or cylindrical) tourniquet cuffs are designed to fit optimally on cylindrically shaped limbs. However, human limbs may be conical in shape (particularly in extremely muscular or obese individuals) which can result in a poor fit, distal sliding of the cuff on the limb during procedure, and the inability to achieve a bloodless field at normal pressure if standard rectangular cuffs are used (Fig 1.6-15).

Contour cuffs have an arc shape and they achieve a smaller diameter distally than proximally when wrapped. Contour cuffs enhance comfort in patients with conical-shaped limbs and reduce the risk of mechanical shearing. Contour tourniquets occlude blood flow at lower inflation pressure than standard rectangular cuffs of equal width, which may be attributed to better cuff fit and more efficient transmission of pressure to deep tissues.

Cuff width

A tourniquet with as large a cuff as possible should be selected. A cuff with a wider bladder occludes blood flow at a lower pressure level than a cuff with a narrow bladder. The lower pressure may reduce the risk of pressure-related injury to the patient. Take special care with small adults and pediatric patients to ensure that the correct cuff width is used and cuff edges do not lie close to the joints of the limb.

Disposable vs reusable cuffs

Sterile, disposable cuffs are available for situations that require placement of a sterile tourniquet near the operative site (eg, when there is a risk of cuff contamination by exposure to excessive bleeding).

Tourniquet system maintenance

Each tourniquet system is designed and manufactured to high industrial standards; periodic inspection and calibration is recommended to ensure continual safe and effective operation.

Periodic maintenance

The unit should be inspected by a qualified technician at 6-month intervals and undergo functional and calibration checks.

Decontamination

- The exterior of the unit may be cleansed with a cloth dampened with appropriate detergent.
- The exterior of cuff hoses may be cleansed using an appropriate detergent or alcohol solution.
- The interior of cuff hoses should not be cleansed.
- Tourniquet cuffs must be decontaminated in accordance with the manufacturer's instructions.

Fig 1.6-15   Standard cylindrical cuff (left); wide contoured lower leg cuff (right).

Testing for leaks

Most pneumatic tourniquet systems are capable of keeping a cuff with a substantial leak inflated. However, it is desirable to keep leaks to an absolute minimum. For this reason, a check for significant leakage is recommended at regular intervals and following any service procedure.

Troubleshooting guide

Automatic tourniquet units come with a set of quick reference cards with instructions for use and for help if there is a problem. These outline a number of possible malfunctions that could occur with the unit and the most likely causes for each breakdown are shown.

Conclusion

Use of a pneumatic tourniquet to produce a bloodless surgical field places the patient at risk of complications. Certain patients because of their size, age, or physical condition are more likely to respond unfavorably to pneumatic tourniquet use than others. Since most complications are pressure related, establish the following preventative measures:

- Conduct an adequate preoperative patient assessment
- Assure an accurate pressure display
- Use a tourniquet cuff that has the proper fit and size and which can maintain occlusion of arterial blood flow at the minimum effective pressure
- Accurately determine systolic blood pressure
- Pay attention to tourniquet cuff pressure
- Inform the surgeon regularly of elapsed tourniquet time

Physicians are responsible for determining the correct cuff pressure and tourniquet time, but ORP share responsibilities for these measures. In addition, ORP assume responsibility for maintenance of the cuff and accessories to ensure proper function and patient safety.

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Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

1.6.4   Air and power supply   Poh Yan Lim, Siew Hong Lau, Donna Russell-Larson

Power equipment

Today we are privileged to have a selection of power instruments (tools) on the market. Power instruments can be driven by compressed air, battery, or electricity, and may be controlled by a hand switch or a foot pedal. Some are highly specialized for single use such as cement removal, while others offer a combination of performance options. Systems like the Synthes Power Drive offer the surgeon options of sawing, drilling, and reaming all within one system. Whatever the choice, each has its own advantages and disadvantages.

The selection of power instruments for use in the operating room (OR) depend on:

- Type of surgery
- Surgeon preference
- Versatility of equipment
- Budget constraints of the department (probably the most important factor)

One system that could be used by multiple services within the OR (ie, orthopaedics, neurosurgery, and craniomaxillofacial) would be cost-effective and ideal; however, this rarely occurs. When selecting power equipment from any manufacturer, the issues to consider are the products' versatility, warranties, and cost-effectiveness.

Owing to the high cost of power equipment it is imperative that OR personnel and/or those responsible for the power equipment be properly trained in the use, care, and maintenance of the tools. Ongoing staff education that adheres to manufacturers' guidelines will prolong the life of power tools and decrease overall maintenance costs.

Performance criteria

Various features are available on power equipment. The following options should be carefully considered when selecting new equipment:

Saw: reciprocating vs oscillating

An oscillating saw moves in a side-to-side motion, while a reciprocating saw moves in a forward and backward motion. Blades of each type are available in various shapes and sizes to accommodate both "macro" (large bone) and "micro" (small bone) surgery.

Drilling: standard vs high speed

Drilling power tools use high speed and low torque. A standard speed drill is generally used to drill a hole in the bone for screw insertion. The drill bit is secured to the drill with a quick-coupling adaptor or universal chuck and key. The universal chuck can also be used to insert a K-wire or Steinmann pin, although an additional wire driver attachment is more versatile.

A high-speed drill (50,000 to 100,000 rpm) can be used for cutting or "polishing" bone using cutting or smoothing/polishing (diamond) burrs and/or fine drill bits. High-speed drills are also used with specialized burrs and attachments for cutting metal and removing bone cement. Some high-speed power drills may require use of a burr guard of appropriate length and size to protect against breakage and/or unexpected detachment of the burr from its hand piece.

Reaming

Power tools with a reaming capability function at low speed and high torque. Many power systems today have an attachment which provides this. The reaming function is used with specific cutting tools to widen, enlarge, or shape the bone; for example, intramedullary reamers for nail insertion. Many instruments designed for reaming use proprietary couplings, and the type and number of adaptors that are needed to link them to the drill body should be considered.

Specialization

A variety of highly specialized power tools include tools specifically designed for fine dissection of bone, cutting metals and plastics, and bone cement removal.

Power source

When selecting a power tool, the type of power source required should be considered. The three possible sources of power are: compressed air or nitrogen; battery power; and electricity.

Compressed air or nitrogen

The obvious advantage of using a power tool that relies on compressed air (or nitrogen) is that it does not require electricity. This may be the decisive factor if working in a hospital which is subject to electrical power failures. Pneumatically driven systems offer the surgeon high power while minimizing hand piece weight. An air-powered tool is controlled either by a hand piece trigger or a foot pedal.

When choosing air-powered tools, the source of the compressed air must be evaluated. Will it be a piped internal supply built into the OR, or come from a portable gas cylinder? When using an internal supply, will the air hose be long enough to span the distance between the wall outlet and the sterile field?

If gas cylinders are to be used, where will they be stored? Are they easily accessible to staff? Who will be responsible for refilling empty cylinders? Staff must be trained in the proper transportation and use of air cylinders.

All air-powered equipment requires use of a hose which can be cumbersome and has a greater risk of contamination during surgery than a battery-powered tool. Importantly, air-powered tools must be used within the manufacturer's recommended operating pressure limit (typically 90–100 psi); thus avoiding damage to the internal mechanism of the hand piece, attachments, and air hose. Air-powered tools must never be operated using oxygen because of the danger of explosion (Fig 1.6-16).

Battery power

Battery-powered tools have the advantage of not relying on any power hose connected to the hand piece, although this is at the expense of some increase in weight. They require an electric battery charger which must be stored in a cool place with access to electrical power points (Fig 1.6-17). It is wise to use power points that are connected to a back-up generator in the event of a power cut. Knowing the lifespan of a battery, the number likely to be required for a particular procedure, and the time required for recharging helps determine the number of batteries and chargers to purchase.

Batteries are available in two types: those that are sterilized (according to the manufacturer's guidelines) before use and those used nonsterile. The latter are placed in a sterile casing before use. The sterile casing remains closed at all times during an operation, and it must never be submerged in water.

Fig 1.6-16   Air-powered tools.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

Electricity

Electrical power tools are similar to pneumatic tools in that they require the use of an electric cord attached to the hand piece for use. Electrical tools can be controlled by a foot pedal, by hand piece trigger, or by both. Some offer a wide range of speeds with constant or intermittent irrigation features. They are generally light, ergonomically shaped, and user friendly. They are also capable of performing multifunctional tasks for many services within the OR. Most require use of an electrical console into which the electrical cord is plugged. The length of a system's electrical cord should be considered when selecting a system. This enables effective planning of the room set up to allow suitable placement of the console and possible electrical extension cords (Fig 1.6-18).

Care and maintenance

Power tools are complex pieces of machinery and are used extensively. Proper care and maintenance are a must to avoid expensive breakdowns. When purchasing a power tool or system, always consider both the maintenance and warranty policy of the manufacturer, and how the manufacturer's sterilization guidelines fit in with institutional sterilization policies. Some companies may be willing to provide educational and other support to personnel in the OR.

Creating a servicing schedule promotes optimal performance of a power tool and prolongs its lifespan. Most important, following the manufacturer's recommendations for use and care of the power tool promotes safety and avoids problems. Proper training of staff with on-going, in-service education is another key factor in protecting these investments. Creating a competency check-off list which includes a demonstration of the care and use of power tools is helpful to assess staff knowledge of a specific power tool or system.

Fig 1.6-17   Battery-powered tool.

Fig 1.6-18   Electrical power tool.

Cleansing precautions

Whenever possible power tools, like other equipment, should be washed in an automatic washer/sanitizer according to the manufacturer's guidelines (see chapter 1.4). If it is necessary to hand wash power tools for any reason, consider the following:

- Never immerse hand piece, hoses, or attachments
- Never clean hand piece with bleach (unless they can be closed), chlorine-based detergents, liquid or chemical disinfectants, or products containing sodium hydroxide, as they degrade the anodized coating
- Ensure washing solution does not enter the air inlet
- Do not use piercing objects for cleansing
- Remove attachments from hand piece before cleansing
- Thoroughly cleanse all cannulated attachments using recommended cleansing brushes (wires) (Fig 1.6-19)
- Manipulate all moving parts of attachments and hand piece to ensure all debris is removed

- After cleansing, rinse attachments under running water to remove cleansing agents, then rinse with distilled water to prevent metal discoloration (Fig 1.6-20)
- Gently shake attachments free of water and wipe surfaces with a clean, lint-free towel

Before sterilization all tools should undergo the following:

- After each use and cleansing, the power tool body and all attachments and hoses/cords must be inspected for wear and damage.
- Hoses/cords should be removed and packed separately or in a separate compartment of the power tool container as hot metal can damage them. This is why hand pieces, attachments, accessories, or tools should never lie on hoses or cords during the sterilization process.
- Lubricate hand piece and attachments after cleansing and before sterilization according to the manufacturer's guidelines.

Fig 1.6-19   Cleansing cannulated hand piece with a brush.

Fig 1.6-20   Rinsing hand piece and attachments.

Authors   Sari Cohen, Poh Yan Lim, Merng Koon Wong, Siew Hong Lau, Donna Russell-Larson

- Do not place hand piece or attachments for sterilization in a "peel pack." Sterilization in a sealed pouch traps moisture which can cause damage to the equipment.
- Use manufacturer's recommended sterilization method.

Batteries
- Batteries should always be fully charged before use.
- Know the shelf life of battery being stored outside of the charger. More charging/discharging cycles may be required for a battery to be fully charged.
- Use only chargers recommended by the manufacturer. Using a charger that does not originate from the manufacturer may result in battery damage.
- Charge batteries within an ambient temperature range of 0–40°C.
- The charging station should always be turned on when a battery is in the charging base. This ensures availability and prevents discharge.
- Attach the battery to the hand piece just before use of the power tool. This saves battery energy and reduces the likelihood of requiring a battery replacement during surgery. Always have more than one battery available for each case.
- Never use damaged batteries; this could harm the hand piece.
- Cleanse batteries according to the manufacturer's recommendations.
- If using batteries that can be sterilized, follow the manufacturer's recommended guidelines.

When using power tools ORP should observe the following guidelines:
- Always engage safety switch when equipment is not in use, and/or changing any attachments, ie, saw blades, burrs.
- Check that all burrs and saw attachments are properly mounted to the power tool attachment before use.
- Assure power cords (air hoses, electrical cords) remain within the perimeter of the sterile field.

- Always inspect power hoses/electrical cords before use for signs of wear or damage. Replace them immediately if faulty. A rupturing air hose can cause serious injury.
- Check pneumatic hoses for leaks. Do not use if a leak is detected.
- Ensure all hand pieces and attachments are properly connected before use.
- If necessary, when using power hoses make sure proper diffusers are connected to air hoses to prevent contamination of the sterile field.
- Continually check hand piece and attachments for overheating. If overheating is noticed, discontinue use and have the item serviced.
- Do not exceed the manufacturers' recommended pressure for operating air power equipment.
- Do not operate a hot-hand piece directly from the autoclave. Operation of a hand piece that is not completely cool and dry may decrease performance and/or reliability. Be aware of the risk of the patient being burnt by a hot-hand piece or attachment due to heat transfer from the metal. Do not immerse the hand piece in liquid or cover it with a damp cloth to cool. Cool only by exposure to room temperature.
- Clean drill bits and burrs after each use. Build-up of bone debris causes reduced cutting efficiency which prolongs cutting and drilling time. Impaired cutting efficiency may cause excessive build up of heat resulting in bone necrosis—an infection risk.
- Discard burrs and saw blades according to the manufacturer's recommendations and/or hospital policy.
- If a foot pedal is used for power control, the user should know exactly where it is situated especially if other foot pedals are being used simultaneously, ie, diathermy foot pedal.
- Protective eyewear should be worn by all ORP when using power tools. This is particularly important when a tool is being used for cutting metal or cement.
- Implementing universal precautions, including protective clothing and following hospital policies when handling and cleansing contaminated instruments prevents staff injury.

Conclusion

Power tools, when used properly, decrease operative time, increase technical accuracy, and improve surgical results. ORP should be familiar with power tools that they might encounter in the OR. The selection of a particular tool will depend on many factors, including surgeon preferences, capabilities and versatility of the power tool/system, and budget constraints. The duration of a tool life is prolonged by following the manufacturer's recommended guidelines, on-going staff education, and compliance with hospital policies.

1.6.4.1   Further reading

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Acknowledgment

2   Principles of trauma care

2.1 Fracture issues

Author   Christopher G Moran

2.1   Fracture issues

2.1.1   Basic principles of fracture management

A holistic approach to the patient, including a full evaluation of the patient, the soft tissues, and the fracture is fundamental to AO philosophy. Using this approach for the internal fixation of fractures resulted in the 1958 development of the four AO principles of fracture management. During the last 50 years, the understanding of the biology and biomechanics of fracture healing has significantly increased, while developments in implant technology have resulted in a massive expansion in the number and type of implants available to the surgical team. However, these four principles have withstood the test of time and are still fundamental to the management of fractures:

- Restore the anatomy
- Establish stability
- Preserve blood supply
- Early mobilization of the limb and patient

The planned application of these basic principles to each patient and each fracture gives the best chance of a good outcome—a return to normal function.

Personality of the injury

The patient must be treated as a whole and not just the fracture in isolation. The management of each fracture depends on three key factors:

- Patient
- Soft tissues
- Fracture

Together these three factors make up the "personality of the injury" (Fig 2.1-1). The final key to fracture management is the health care environment: What facilities are available? What implants? What are the skills and experience of the surgical and nursing teams?

Patient

Soft tissues

"Personality" of the injury
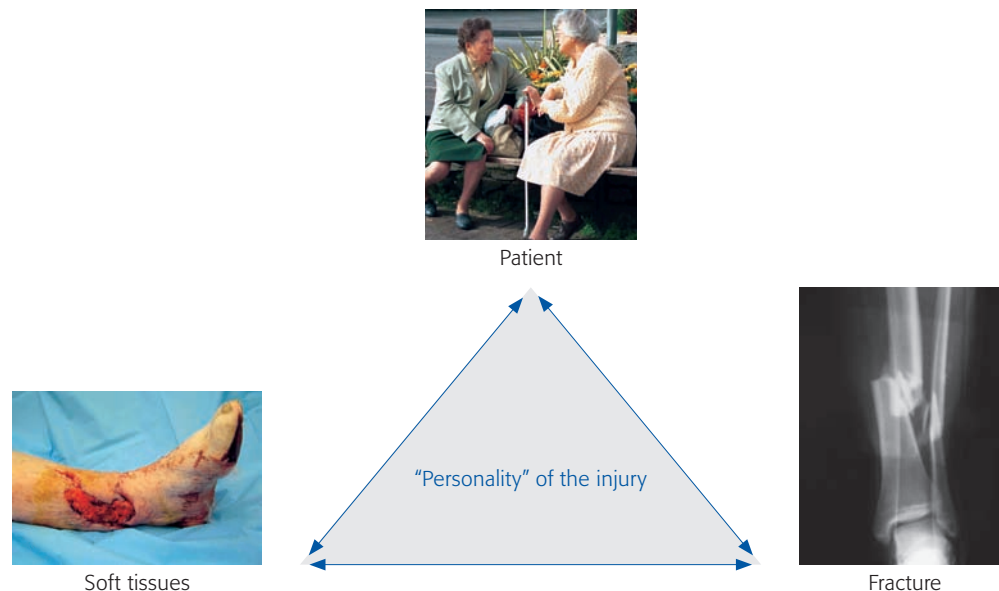
Fracture

Fig 2.1-1   The "personality" of the injury depends on three factors—the fracture, the associated soft-tissue injury, and the patient's general and injury-related health.

Patient—general factors

Many factors are essential when evaluating a patient. Age significantly influences fracture healing and is also important in rehabilitation. Children tend to heal and rehabilitate quickly while elderly, frail patients are at risk of additional complications, such as chest or urinary tract infections and decubitus ulcers. Occupation is also an important factor; one of the goals of fracture management is to return the patient to work, and the requirements of a heavy manual worker, an office employee, a fine-skilled worker, or a musician are different.

Medical comorbidities must be assessed in all patients, which may influence the choice of surgical procedure as well as the method of anesthesia. In the elderly, peripheral vascular disease and ulceration with poor circulation may prohibit the internal fixation of lower limb fractures. People with diabetes require optimal control of blood glucose levels to reduce the risk of infection and patients with neurological disease, such as Parkinson disease, may have difficulty complying with postoperative rehabilitation. Patients with pathological fractures due to malignant disease also have specific nursing and surgical requirements.

A patient's social circumstances may radically alter the ability to undertake activities of daily living and cause major problems with rehabilitation. This is especially true in the elderly patients when trivial injuries can permanently threaten their independence. Psychiatric disorders may also have an important influence on patients' compliance. Patients with drug or alcohol dependence can be challenging to treat and often fail to follow postoperative instructions.

Patient—injury-related factors

All patients must have a thorough assessment in the emergency department. This should start with an assessment of the airway, breathing, and circulation according to the advanced trauma life support principles (ATLS). The neck, spine, and pelvis must be protected at all times. The primary survey and initial treatment are aimed at saving life (Fig 2.1-2). Few fractures, except severe pelvic fractures and open fractures with massive hemorrhage, are immediately life-threatening. The evaluation and primary treatment of fractures takes place in the secondary survey which examines the patient from head to toe.

Soft tissues

A systematic examination of the soft-tissue injury associated with a fracture is essential. In every case this should include:

Skin: look for open wounds, contamination with dirt, clothing or foreign bodies, abrasions, bruising, blistering, swelling, and closed degloving injuries (this is a shear injury when the skin becomes disconnected from the underlying fat and fascia).

Muscle: function should be tested by asking the patient to gently move the hand or foot distal to the injury site.

Compartment syndrome: this occurs when there is increased pressure in a closed fascial compartment resulting in local tissue ischemia. Most tissue in a compartment is muscle and ischemic

Fig 2.1-2   Polytrauma is best managed by a well-organized, multidisciplinary trauma team.

Author   Christopher G Moran

muscle goes into spasm causing severe pain that gets worse with active or passive movement. A compartment syndrome is diagnosed clinically and is a surgical emergency. It needs immediate operation to release the pressure by performing a fasciotomy and restoring blood flow to the muscle. This procedure prevents muscle death. A surgeon must be alerted immediately if there is concern that a patient has compartment syndrome—increasing pain in the affected compartment made worse by passive stretching of that muscle.

Nerves: nerves may be injured by direct impact, penetrating wounds, displaced fracture fragments, or they may be stretched as the fracture deforms. All nerves that cross a fracture must be examined for both motor and sensory function and this assessment is usually combined with the evaluation of muscle function. Assessment is difficult in children and patients with head or spinal injuries.

Blood vessels: the circulation distal to the injury must be evaluated in all fractures. Capillary refill is tested and should be less than 2 seconds. The pulses must be carefully palpated. An absent pulse must never be ignored—it is a sign of arterial injury and a surgeon must be alerted immediately. The diagnosis of arterial injury can be difficult in young adults as the collateral circulation may maintain the blood supply to the skin, which can remain pink and can still give a signal on a pulse oximeter, despite there being an inadequate blood supply to the muscles. Failure to restore adequate circulation within 4–6 hours causes irreversible ischemic damage and results in amputation. Vascular problems therefore require immediate action. Any deformity must be corrected usually by gentle traction and, if the pulse remains absent, immediate surgical exploration to restore the circulation is required. This treatment should not be delayed to get an arteriogram.

Fracture

Clinical evaluation: the cardinal signs of fracture are tenderness, abnormal movement, and bone crepitus. The patient will hold or splint the limb to avoid painful movement and there may be obvious deformity, bruising, and swelling at the fracture site. Clinical examination must be gentle to avoid excessive pain and further damage to the soft tissues. Nurses and surgeons must avoid moving the fracture if at all possible as this causes severe pain. The patient must be given adequate pain relief and the fracture splinted as soon as possible. This gives good pain relief and prevents further soft-tissue damage. Neurovascular examination must be performed before and after the fracture is splinted (see above). The evaluation must include the whole bone and the joint above and below the fracture. The recognition of injury patterns is helpful and a thorough history of the injury should be obtained, as this gives an indication of possible additional injuries.

X-rays: these are essential for diagnosis and planning of treatment. All fractures should have two x-rays at right angles to fully evaluate any deformity. This usually requires anteroposterior and lateral views; oblique x-rays are needed in some situations, eg, acetabular fractures. In addition, x-rays must include the joint above and below the fracture (see chapter 2.7). In certain situations, such as the wrist, x-rays do not include the joint above (the elbow), thus a thorough clinical examination of the joint must be performed and noted in the medical records.

It is possible to plan the treatment of most fractures using these x-rays but complex injuries and fractures that involve a joint may require additional information from a computed tomographic scan (Fig 2.1-3). A magnetic resonance imaging scan is occasionally required to evaluate soft-tissue injuries associated with fractures, especially possible knee ligament injuries related to fracture dislocations of the knee. Magnetic resonance imaging can also be helpful for the diagnosis of occult fractures that are sometimes not visible on plain x-rays, such as stress fractures and undisplaced fractures of the hip.

Health care environment

Patients must receive proper care in the appropriate setting. When planning surgical treatment of a fracture, the surgeon must take into account the facilities and equipment available, including implants, radiological imaging, and the correct operating table.
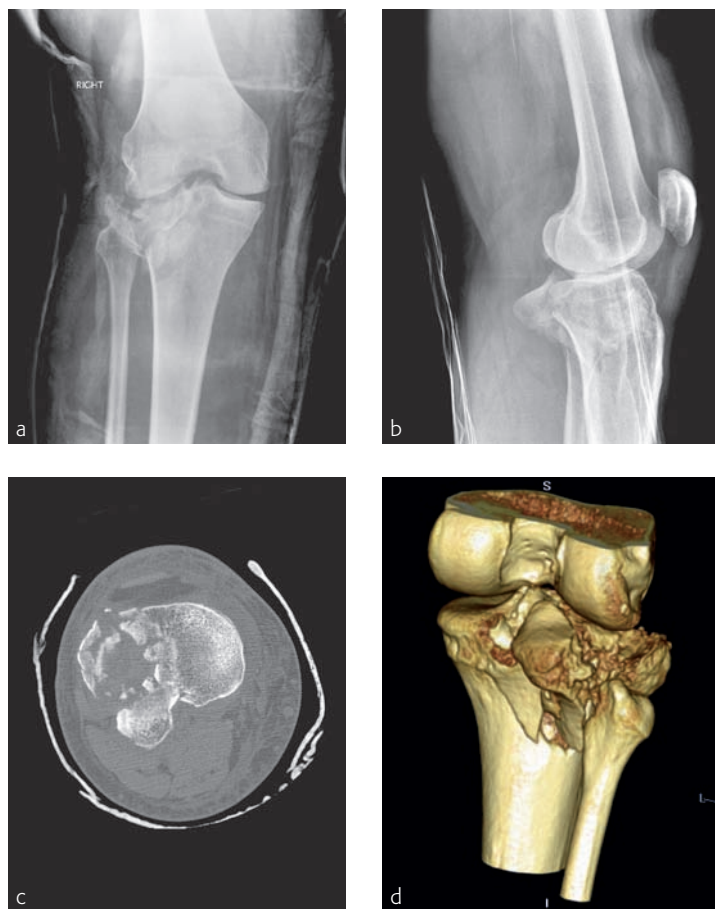
Fig 2.1-3a–d
a–b   AP and lateral x-rays of a fracture of the lateral tibial plateau.
c   A CT scan of the same fracture provides more detailed information.
d   A 3-D CT reconstruction of the fracture can be useful when planning
      fracture management.

The skills, training, and experience of the operating room personnel (ORP) should also be considered. Rather than working at night with inexperienced ORP, it is better to undertake emergency surgery the next morning with an experienced team who are familiar with the equipment (and who have had a good night's sleep). Surgeons must make an honest appraisal of their own skills and experience. It is better to transfer patients with rare or complex injuries to a trauma center where additional facilities and surgical expertise are available.

Communication

Clear communication among physicians, ORP, patients, and relatives is essential. Once the surgeon has evaluated the personality of the injury, he or she must formulate a treatment plan and communicate this effectively to the entire team managing the patient. Planning is essential and all surgery, including emergency operations, should be planned procedures. As the saying goes, "Failure to plan is planning to fail." There are three key facets to the treatment plan:

Surgical strategy: the overall treatment plan for the patient, including preoperative investigations, surgical and medical treatment, and rehabilitation. With a polytrauma patient, good communication with other specialists is important to set priorities and determine the sequence and timing of multiple procedures. It is essential that one senior surgeon takes overall responsibility for the patient's management and this is usually the trauma surgeon.

Surgical tactic: the overview and plan for each complete episode in the operating room. This allows the surgeon, anesthetist, and ORP to prepare for each operation. Key information that must be communicated includes the planned procedure, patient position, type of operating table, instruments and implants required, need for intraoperative radiology or blood transfusion, splints, and special postoperative requirements such as an intensive care bed.

Author Christopher G Moran

Surgical plan: the detailed drawing that the surgeon must prepare for each fracture fixation. This allows the surgeon to mentally rehearse the operation, determine the anatomical approach to the fracture (and thus the patient position), and which implants and instruments are needed. Potential intraoperative complications and problems can be anticipated and avoided and ORP informed that additional equipment could be required.

Good communication with patients and relatives is imperative. They should have a clear understanding of the nature of the injury, intended surgical treatment, and the rehabilitation program. A realistic expectation of the outcome is essential and good communication with patients usually prevents a breakdown in trust that can lead to litigation.

2.1.2 Why fix fractures?

Most fractures heal without surgery and the main reason for fixing fractures is to improve the final functional outcome for the patient and to reduce long-term risks, such as posttraumatic arthritis. For patients with severe multiple injuries, early fracture stabilization may aid nursing care in the intensive care unit and reduce the risk of serious chest complications.

The decision to fix a fracture depends on the personality of the injury and the available health care resources. In general, the following are good indications to fix fractures:
- Long-bone fracture stabilization in polytrauma especially femoral shaft fractures
- Open fractures in adults
- Displaced intraarticular fractures
- Displaced forearm shaft fractures in adults
- Fractures with a high risk of nonunion, eg, displaced intra-capsular hip fractures

- Fractures in elderly patients when nonoperative treatment would require prolonged immobilization
- Pathological fractures for pain relief and palliative care
- Displaced fractures through the growth plate in children

Fracture fixation is also generally used when it is difficult to prevent deformity of displaced fractures using nonoperative methods because local muscles forces are difficult to overcome with plaster casts or traction. These fractures usually require prolonged immobilization and long periods in hospital. Examples include:
- Subtrochanteric fractures of the femur
- Supracondylar fractures of the femur
- Shaft fractures of the femur
- Displaced pelvic fractures
- Displaced, unstable tibial fractures

Fracture fixation can speed up rehabilitation and allow an earlier return to work.

2.1.3 How do fractures heal?

Bone is unique within the body as it is the only tissue that heals by regenerating normal tissue (bone) rather than scar tissue. Normally, fractures heal by producing a large mass of immature bone, called callus, as quickly as possible. This restores the strength and continuity of the bone and allows an early return to function. Over the next 6–18 months, this immature bone is then slowly remodeled to produce the normal structure of the bone, including Haversian canals. Fracture healing with callus occurs when there is some mobility at the fracture, either in nature (when an animal must remain mobile to survive) or when fractures are splinted with plaster casts or traction devices. The same mode of healing is evident when fractures are fixed, allowing some controlled motion at the fracture site (relative stability). Good examples are external

fixation and intramedullary nails. This type of healing is termed indirect or (confusingly) secondary bone healing (Fig 2.1-4).

Internal fixation, so that there is no movement at the fracture site under functional load (absolute stability), allows bone to heal in a different way. Bone is a living tissue that is constantly wearing out and being replaced at a microscopic level. In the absence of movement, bone heals by using these mechanisms with the fracture slowly being replaced by living bone. There is no callus formation and the process is much slower than natural indirect bone healing. Because this type of bone healing uses the normal remodeling process of bone it is called direct or primary bone healing (Fig 2.1-5).

It is important to recognize that the surgeon determines the type of bone healing by using different fixation techniques that produce different mechanical environments. Absolute stability results in no movement and direct bone healing without callus. Relative stability allows some controlled movement at the fracture site, resulting in callus formation and indirect bone healing. Absolute stability techniques are used to provide and maintain anatomical reduction of the fracture (eg, simple, diaphyseal forearm fracture) if this is required to restore normal function. Thus, direct bone healing is a secondary effect of this method and is not the primary aim. Neither primary nor secondary bone healing is better than the other: the surgeon must choose the appropriate method to stabilize each fracture and then apply it correctly to obtain fracture healing.
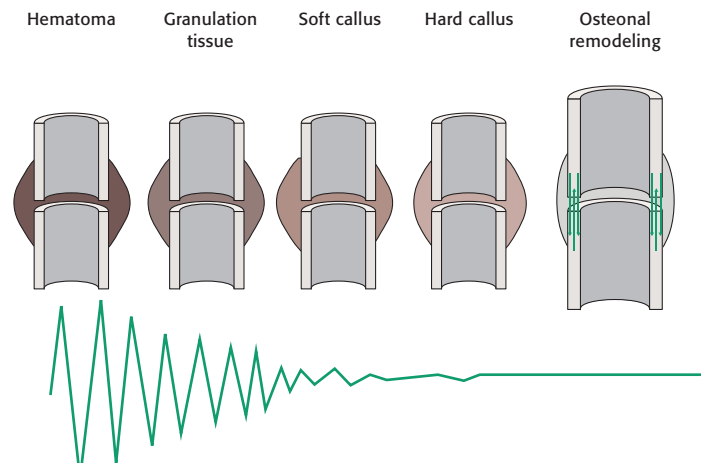
Fig 2.1-4   Stages of indirect fracture healing.
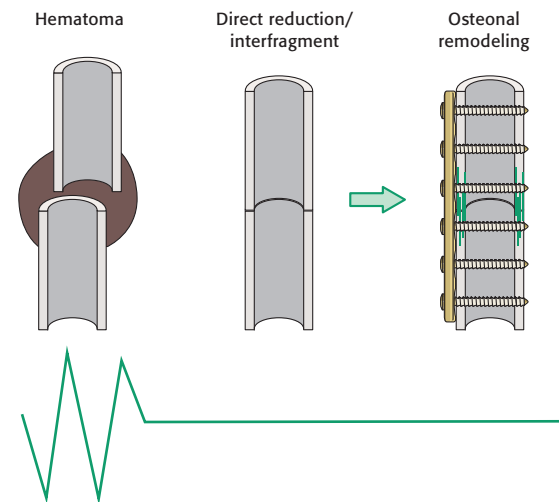
Fig 2.1-5   Stages of direct fracture healing.

Author   Christopher G Moran

Fixation of fractures must provide enough stability to allow early mobilization of the limb and the patient. This is one of the key AO principles. Any surgery must also minimize additional damage to the blood supply of the bone. Thus, the surgeon must use carefully planned incisions, handle all soft tissues gently, and avoid removing periosteum and muscle attachments from fracture sites so that the maximum possible blood supply is maintained. By applying the AO principles, the surgeon should produce the best possible biological and mechanical environment to allow early mobilization of the limb and rapid fracture healing.

2.1.4   Further reading

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2.2 Fracture classification

Author   James Kellam

2.2   Fracture classification

Fracture classifications have multiple purposes. They should facilitate communication among physicians and be useful for documentation and research. For clinical relevance, they should have a value to guide physicians in their planning and management of fractures. They should also inform both physicians and patients of the prognosis for the injury. The basis for all clinical activity, be it assessment and treatment, investigation and evaluation, or learning and teaching, must be sound data which is properly assembled, clearly expressed, and readily accessible. Numerous classification systems have been proposed in orthopaedics but only a small number of them are widely accepted in practice, such as the Müller AO/OTA Classification of fractures. Even fewer have stood the rigorous task of evaluation.

2.2.1   Principles of Müller AO/OTA Classification of Fractures—Long Bones

Overall structure and attributes

Any classification system should be suitable for the acquisition, storage, and retrieval of data. The Müller system presents a way not only to document fractures but also to understand them in biomechanical and biological terms. The system is based on a well-defined terminology which allows the surgeon to consistently describe the fracture in as much detail as is required for the clinical situation. The description is the key to the classification and this then forms the basis for the alphanumeric code which makes it suitable for computerization, documentation, and research. The first aim of the surgeon is to identify what Müller has referred to as the "essence of the fracture." This is the attribute that gives the fracture its particular identity and enables it to be assigned to one particular type.

Classification is an ongoing process which depends on the information available to the surgeon at any given time. This process of classification is known as the diagnostic method. To make a diagnosis, information concerning the anatomical location and morphological characteristics of the fracture is obtained. This consists of a description of the location (ie, which bone is fractured and which part of the bone is affected?), followed by a fracture type (ie, how many fragments are involved?), and finally the morphological characteristics of a fracture (ie, what does the fracture look like?). This process provides useful clinical information for the physician to determine treatment. Only when all information concerning the fracture is collected may the classification process be considered complete.

Fracture localization: bones and segments

Each major long bone (humerus, radius and ulna, femur, and tibia and fibula) is named and then numbered (Fig 2.2-1). It should be noted that the two-paired bones, that is the radius and ulna, and the tibia and fibula, are regarded as one entity or group. Each long bone consists of three segments. There are two end segments (proximal and distal) and these are joined by a middle portion known as the diaphysis or shaft. The end segment consists of the metaphysis and articular surface. The extent of the end segments is defined as a square whose sides are the same length as the widest part of the epiphysis of the segment in question. Each of the segments in the bones is also numbered (Fig 2.2-2). There is a final segment, the malleolar segment, which is an exception to the rule. The pattern of these ankle fractures is determined by the relationship between the bones of the ankle mortise and their associated ligaments. The rule of defining the end segment cannot be applied. The Weber classification is universally accepted for this segment.

To assign each fracture to a segment, the center of the fracture must be determined. For a simple fracture, where there are only two bone fragments, this is apparent. It is the midpoint of an oblique or spiral fracture, and in a transverse fracture it is obvious.

91-

9- Craniomaxillofacial bones

92-

51-

52-

15-

15- Clavicula

11-

14-

14- Scapula

1- Humerus

12-

5- Spine

13-

53-

21-

61-

2- Radius/ ulna

22-

6- Pelvis/acetabulum

23-

31-

62-

32-

7- Hand

3- Femur/patella

33-

34-

41-

42-   4- Tibia/fibula

43-

44-

8- Foot
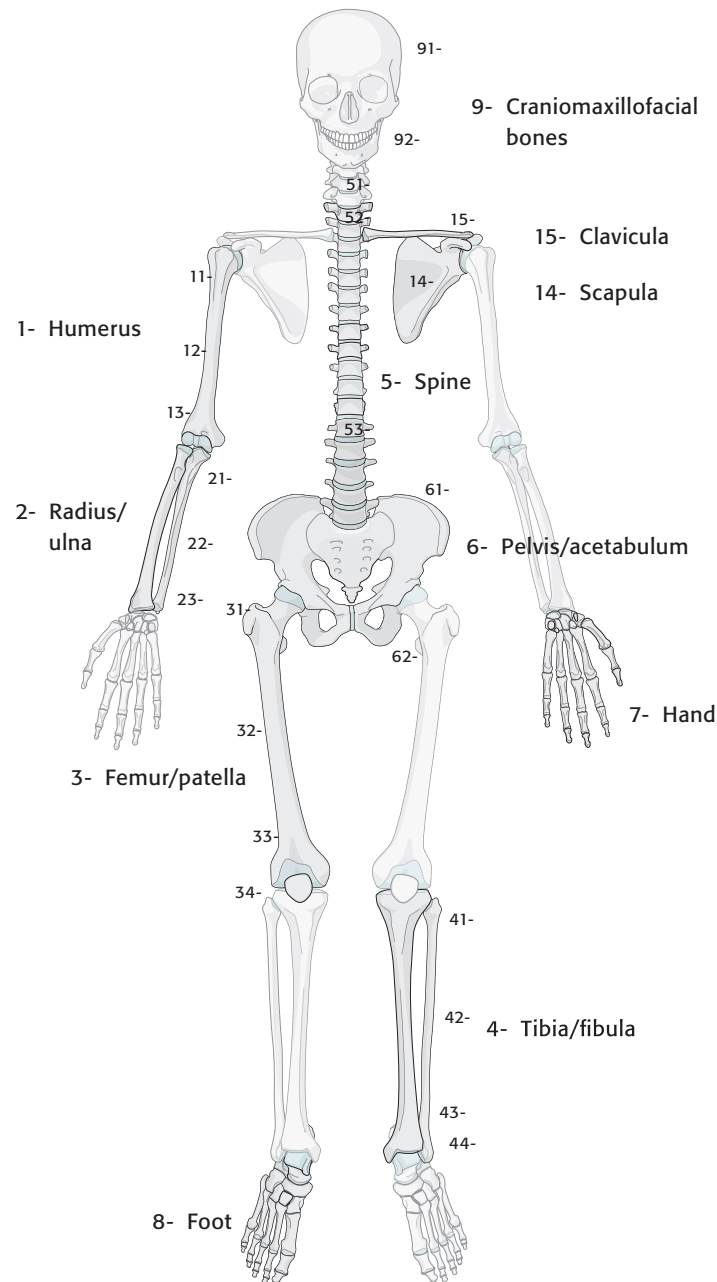
A wedge fracture has a center which is the broadest portion of the wedge or the mid portion of the fragmented area when reduced. For complex fractures, where there are many bone fragments, the center may well have to be determined after reduction when the full extent of fragmentation is determined. This may mean that the surgeon can only give a final classification after surgical treatment. A displaced articular fracture will always be classified in an end segment regardless of its diaphyseal extension, since the articular injury is the most important for treatment and prognosis.

Fig 2.2-1   Müller AO/OTA Classification for numbering the anatomical location of a fracture in three bone segments (proximal = 1, diaphyseal = 2, distal = 3).

Author   James Kellam

2.2.2   Describing fracture morphology

The description of the morphology of a fracture is determined by a set of precisely defined rules. Following these rules allows the surgeon to classify a fracture according to its type, group, and subgroup. For all fractures the surgeon classifies the fracture by answering a well described set of questions. Müller and colleagues refined this process into a binary-type questioning. This means that there is either a yes/no or either/or answer. Different rules apply to fractures in the middle segments of long bones (diaphyseal) and fractures in the end segments (articular or metaphyseal)

Diaphyseal fractures

The questions are:
1. Which bone? Humerus, radius and ulna, femur or tibia (Fig 2.2-1)
2. Which segment? Proximal end segment, middle segment (diaphysis), or distal end segment (Fig 2.2-1)
3. Which type? (Fig 2.2-2)
   A. A simple fracture in which there are only two pieces of bone
   B. A wedge fracture—there are more than two pieces of bone but once reduced the main fragments will have some contact
   C. Complex—three or more fragments. No contact between main fragments after reduction
4. Which group? (Fig 2.2-3)
   1. Spiral fractures
   2. Oblique fractures
   3. Transverse fractures

End segment fractures (metaphyseal and articular)
The questions are:
1. Which bone?—Humerus, radius and ulna, femur, or tibia (Fig 2.2-1)
2. Which segment—proximal or distal end segment (Fig 2.2-1)
3. Which type? (Fig 2.2-2)
   A. Extraarticular—no involvement of articular surface
   B. Partial articular—part of the articular surface is involved leaving the other part attached to the diaphysis
   C. Complete articular—articular surface involved. Metaphyseal fracture completely separates articular component from diaphysis
4. Which group? (Fig 2.2-4)
   A. Extraarticular fractures:
      1. Simple fracture with two pieces of bone
      2. Wedge fracture
      3. Multifragmentary fracture
   B. Partial articular fractures:
      1. Split
      2. Depression
      3. Split depression
   C. Total articular fractures:
      1. Simple articular fracture with a simple metaphyseal fracture
      2. Simple articular fracture with a complex metaphyseal fracture
      3. Complex articular fracture with a complex metaphyseal fracture
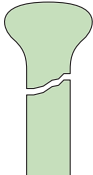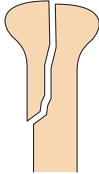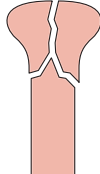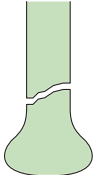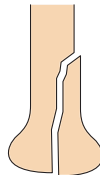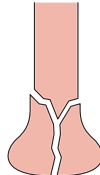
Segment	Type		
	A	**B**	**C**
1 Proximal			
	Extraarticular	Partial articular	Complete articular
	No involvement of displaced fractures extending into the articular surface	Part of the articular component is involved, leaving the other part attached to the meta-/diaphysis	Articular surface involved, metaphyseal fracture completely separates articular component from the diaphysis
2 Diaphyseal			
	Simple	Wedge	Complex
	One fracture line, cortical contact between fragments exceeds 90% after reduction	Three or more fragments, main fragments have contact after reduction	Three or more fragments, main fragments have no contact after reduction
3 Distal			
	Extraarticular	Partial articular	Complete articular
	No involvement of displaced fractures extending into the articular surface	Part of the articular component is involved, leaving the other part attached to the meta-/diaphysis	Articular surface involved, metaphyseal fracture completely separates articular component from the diaphysis

Fig 2.2-2   Definitions of fracture types for long-bone fractures in adults according to Müller AO/OTA Classification.

Author   James Kellam

Type	Group		
	1	2	3
A Simple	Spiral	Oblique	Transverse
B Wedge	Spiral	Bending	Multifragmentary
C Complex	Spiral	Segmental	Irregular

Fig 2.2-3   Classification of fractures of the diaphysis into the three fracture groups according to Müller AO/OTA Classification.
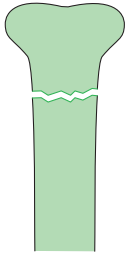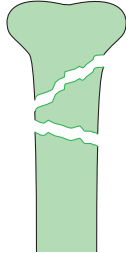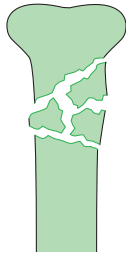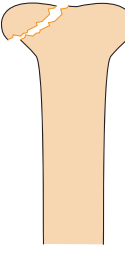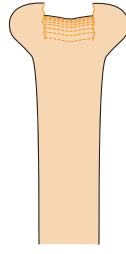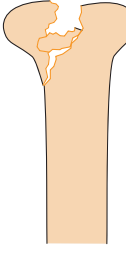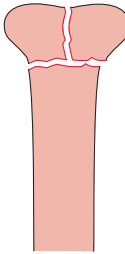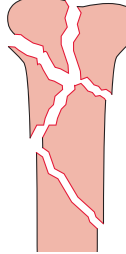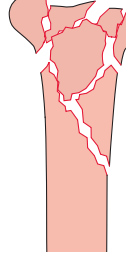
Type	Group		
	1	**2**	**3**
A **Extraarticular**	Simple	Wedge	Complex
B **Partial articular**	Split	Depression	Split-depression
C **Articular**	Simple articular, simple metaphyseal	Simple articular, complex metaphyseal	Complex articular, complex metaphyseal

Fig 2.2-4   Classification of fractures of the diaphysis into the three fracture groups according to Müller AO/OTA Classification.

Author   James Kellam

2.2.3   Conclusion

Fracture classification is the categorization of a fracture. It is used for documentation and research and gives surgeons and patients information about treatment options and prognosis. The process of obtaining this documentation is the process of diagnosis. Throughout this process, the surgeon will learn to understand the fracture, that is "the essence," and be able to determine its treatment. This system is based on a well-defined series of definitions which are an important aspect in clinical practice.

Finally, there are attempts at the present time to determine whether fracture classifications are valid. In other words, can they be used reproducibly and do they represent what is truly seen clinically so that clinical outcome research can be based on solid data.

2.2.4   Classification terminology

Articular: fractures which involve the joint surface. They are subdivided into partial articular and complete articular fractures.
Articular, partial: only part of the joint is involved while the remainder stays attached to the diaphysis.
Articular, complete: the joint surface is fractured and the entire joint surface is separated from the diaphysis.
Complex: fractures with one or more intermediate fragments in which there is no contact between the main fragments after reduction.
Extraarticular: fractures that do not involve the articular surface.
Multifragmentary: a fracture with more than one fracture line so that there are three or more pieces. It includes wedge and complex fractures.
Multifragmentary depression: a fracture in which part of the joint is depressed and the fragments are completely separated.
Depression: an articular fracture in which there is only depression of the articular surface, without a split.

Split: articular fracture in which there is a longitudinal metaphyseal and an articular fracture line, without any additional articular surface lesion.
Simple: there is a single fracture line producing two fracture fragments. Simple fractures of the diaphysis or metaphysis are spiral, oblique, or transverse.
Wedge: fracture complex with a third fragment in which, after reduction, there is some direct contact between the two main fracture fragments.

2.2.5   Further reading

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2.3 Soft-tissue injuries

Author   David Volgas

2.3   Soft-tissue injuries

2.3.1   Introduction

Soft-tissue injury is perhaps the single most important aspect in orthopaedic surgery. Soft tissues are often damaged as a result of an external injury, but they may also be injured by poor surgical technique. In both trauma and elective surgery, problems with soft-tissue healing account for most complications seen in orthopaedic practice. It is therefore worth investing time and practice to learn the principles of soft-tissue handling and management to avoid their further injury and to optimize their recovery after any damage.

2.3.2   Soft-tissue anatomy

It is critical to know the anatomy of muscle, subcutaneous tissue, and skin to understand how to avoid soft-tissue complications. In general, muscle has blood supply from a named artery which passes near it. This either supplies the muscle by a single large vessel near its origin, by multiple segmental vessels arising from the named artery as it travels the length of the muscle, or by a combination of these patterns. The blood supply to a specific muscle may be found in any book which describes flaps.

Bone has two sources of blood supply, endosteal and periosteal (Fig 2.3-1). The periosteal blood supply comes through the heavy fascial attachments associated with muscle origins or insertions. It supplies the outer third of the cortex. The endosteal blood supply runs longitudinally along the medullary canal and originates from the nutrient vessels to the bone. This blood supply contributes branches which supply the inner two-thirds of the cortex. This arrangement may be reversed following a fracture, which usually disrupts the endosteal blood supply, leaving bone blood-flow dependent on the periosteal supply, which is in turn largely dependent on the overlying muscle. Fracture healing is likely to

be delayed when there is poor blood supply to the bone if there is no overlying muscle (such as over the distal tibia), or if the muscle is damaged at the time of injury or subsequently, during surgery.
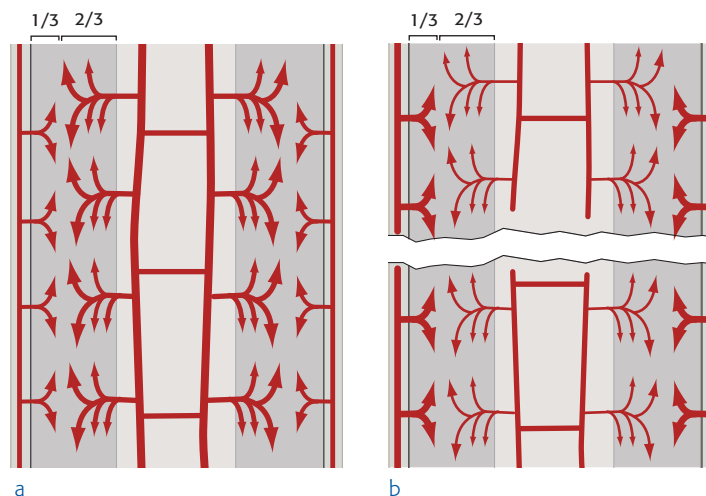
Fig 2.3-1a–b
a   Intact bone: 2/3 of blood supply comes from medullary vessels; 1/3 from periosteal vessels.
b   Fractured bone: reduction in blood supply from medullary vessels (1/3); increased blood supply periosteal vessels (2/3).

Skin receives its blood supply from perforating vessels which arise from the fascia overlying muscles and tendons. Figure 2.3-2 shows the typical arrangement of blood vessels from deep to superficial. This fascial plexus (1), in turn, is supplied by vessels which run through or around muscles (2). Trauma such as shear stress across the skin and poor dissection technique may destroy these vessels and cause necrosis of the skin.

There are areas of the body which are particularly sensitive to traumatic or surgical shear injury. These areas include the ankle, calcaneus, tibial plateau, and elbow that are vulnerable to degloving and skin necrosis, especially when surgery is performed in the acute setting after trauma.

2.3.3 Classification of soft-tissue injury in closed fractures

There are two main classification systems for soft-tissue injury in closed fractures. The Tscherne classification (Tab 2.3-1) was an early attempt to quantify the degree of injury based on the physical appearance of the wound and fracture pattern. This classification system is still used by trauma surgeons because of its ease of use, but is limited by poor interobserver reliability. The AO soft-tissue grading system (Tab 2.3-2) is more complex and attempts to independently assess injury to the skin, muscle, subcutaneous tissue, and the neurovascular system. It is not widely used in clinical practice but is especially useful in research. Soft tissue can also be assessed by simply looking critically at the skin and subcutaneous tissue for signs of significant trauma:
- Fracture blisters
- Contusion in the soft tissue
- Degloving of the skin
- Subcutaneous hematoma

Fig 2.3-2 Blood supply to the muscles and skin; subcutaneous skin illustrating the vulnerable perforating vessels. This fascial plexus (1), in turn, is supplied by vessels which run through or around muscles (2).

Author   David Volgas

	Grade 0	Grade I	Grade II	Grade III
Soft-tissue injury	No or minor soft-tissue injury	Superficial abrasion or contusion	Deep contaminated wounds or deep contusions; imminent compartment syndrome	Extensive soft-tissue contusion, destruction of muscle, significant degloving, compartment syndrome, vascular injuries
Fracture pattern	Indirect fracture, simple pattern	Pressure from fracture fragments on skin	Medium-to-severe fracture patterns	Severe comminution
Energy of injury		Low- or medium-energy injury	Medium- or high-energy injury	High-energy mechanism of injury

Tab 2.3-1   Tscherne classification (closed fractures).

Closed skin (integument) lesions (IC)	Open skin (integument) lesions (IO)	Muscle/tendon injury (MT)	Neurovascular injury (NV)
IC 1 No skin lesion	**IO 1** Skin breakage from inside out	**MT 1** No muscle injury	**NV 1** No neurovascular injury
IC 2 No skin laceration but contusion	**IO 2** Skin breakage from outside in < 5 cm, contused edges	**MT 2** Circumscribed muscle injury, one compartment only	**NV 2** Isolated nerve injury
IC 3 Circumscribed degloving	**IO 3** Skin breakage from outside in ≥ 5 cm, increased contusion, devitalized edges	**MT 3** Considerable muscle injury, two compartments	**NV 3** Localized vascular injury
IC 4 Extensive, closed degloving	**IO 4** Considerable, full-thickness contusion, abrasion, extensive open degloving	**MT 4** Muscle defect, tendon laceration, extensive muscle contusion	**NV 4** Extensive segmental vascular injury
IC 5 Necrosis from contusion		**MT 5** Compartment syndrome/crush syndrome with wide injury zone	**NV 5** Combined neurovascular injury, including subtotal or even total amputation

Tab 2.3-2   Müller AO/OTA soft-tissue classification.

2.3.4 Soft-tissue handling

Soft-tissue handling is perhaps the most important skill for a surgeon or assistant to learn. As already indicated, it is critical to avoid additional damage to the skin and muscle to minimize the incidence of infection, decrease wound problems, and maintain blood supply to the underlying bone, particularly where it has been fractured. While some procedures are considered routine and rough handling of the soft tissue may not have a significant effect on healing, surgeons and assistants should get into the habit of treating all wounds with caution. There are no surgical procedures that have a zero incidence of skin problems.

Soft-tissue handling begins with appropriate handling of the limb. Limbs are usually splinted when the patient arrives in the operating room. There may be an external fixator in place. Most splints will have to be removed before disinfection, but there are times when only a single injury will be addressed or surgery will be staged. For example, some surgeons prefer to leave a fractured calcaneus in a splint while the leg is positioned for an intramedullary nail of the femur. Likewise, many surgeons leave external fixator pins in place for use in the case with a femoral distractor or an external fixator. Operating room staff should consult the surgeon to determine the plan for removal of any immobilization.

During skin preparation care should be taken not to put excessive traction on injured extremities, and to avoid excessive deformity. The fractured limb should be supported. This may involve a second person who supports the extremity until the unstable area has been prepared. Excessive traction or allowing the extremity to sag significantly can lead to further muscle laceration, bleeding, and stretching of the nerves and vessels. In rare cases this has been reported to cause iatrogenic injury to nerves and vessels.

Certain surgical preparation solutions may be more toxic to tissues, especially in open fractures. The use of betadine or alcohol in open fractures is not recommended because of possible tissue toxicity. Aqueous chlorhexidine is usually preferred in these situations. The surgeon needs to be consulted to determine the choice of solution for skin preparation.

Retraction should always be as gentle and deep as possible. The more superficial the retractors are placed in the wound, the more shear is applied to the delicate vessels which supply the skin. Likewise, the further subcutaneous tissue is retracted from its perforating vessels, the greater the risk of skin necrosis. Therefore, as a rule, skin and subcutaneous tissue must be retracted only as much as is needed to visualize the fracture. Also, although sharp retractors are more likely to damage tissue because they penetrate the subcutaneous tissue, they do not require as much effort to hold in place, thus paradoxically they may do less damage. Whichever retractor is used, only enough force should be applied to expose what the surgeon needs to see. This is critical around areas which have poor blood supply such as in the region of the ankle.

Forceps should be used only with the minimal amount of pressure required to pick up tissue. In general, forceps with teeth can be used to gently retract soft tissue without crushing the tissue. Forceps without teeth require more crushing pressure to pick up the tissue; however, both can injure the tissue if used with more pressure than required.

Dissection should be vertical (Fig 2.3-3) in high-risk areas. This particularly applies in any area which does not have underlying muscle, when undermining of the skin should be avoided. Sharp dissection down to the fracture and careful retraction of the soft tissues will minimize the risk of injury to soft tissue.

Electrocautery should be used with care. In tumor surgery, blood loss may be rapid and electrocautery may be used relatively indiscriminately on vessels which represent neovascularization. However, around joints, it must be used sparingly to avoid necrosis of the edge of the wound.

Author   David Volgas
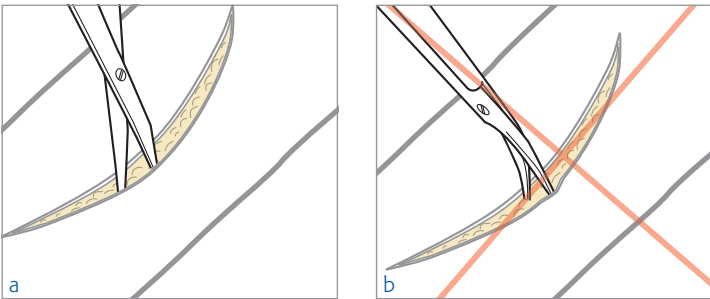
Fig 2.3-3a–b
a   Correct: Vertical dissection along the line of the incision should be performed.
b   Incorrect: Horizontal dissection that separates the skin from the underlying fascia must be avoided.

2.3.5   Open fractures

Open fractures have a break in the skin which communicates with the fracture. Unattended, an open fracture is at significant risk of developing the serious complication of an infection at the fracture site.

The modified Gustilo-Anderson classification is widely used for open fractures (Tab 2.3-3). The key components of the classification system are the energy of the injury, degree of periosteal stripping, and the degree of contamination of the wound.

- Type I injuries are those which involve a low-energy injury such as fall from standing high, minor periosteal stripping, and minimal contamination. They are often considered "inside-out" injuries.
- Type II fractures have a larger skin defect, involve more energy, and have more periosteal stripping than type I injuries.
- Type III injuries are the most severe with a wide zone of injury, much periosteal stripping, a large-skin defect, and a high risk of contamination.

Type	Description
I	Skin wound <1 cm
	Clean
	Simple fracture pattern
II	Skin wound >1 cm
	Soft-tissue damage not extensive
	No flaps or avulsions
	Simple fracture pattern
III	High-energy injury involving extensive soft-tissue damage
	Or multifragmentary fracture, segmental fractures, or bone loss irrespective of the size of skin wound
	Or severe crush injuries
	Or vascular injury requiring repair
	Or severe contamination including farmyard injuries
IIIA	Adequate soft-tissue cover of bone despite extensive soft-tissue damage
IIIB	Extensive soft-tissue injury with periosteal stripping and bone exposure
	Major wound contamination
IIIC	Open fracture with arterial injury requiring repair

Tab 2.3-3   Gustilo-Anderson Classification of open fractures.

The size of the skin defect is relevant but should not be used alone to judge the type of fracture. Certain injuries must be considered as type III injuries regardless of the size of the skin wound. This includes those with obvious gross contamination (such as happen on a farm), or those injuries that are the result of high-energy transfer. High-energy injuries include a high-speed motor vehicle injury, gun shot wounds caused by hunting and assault rifles or shotguns at short range. A vascular injury requiring repair is always considered a type IIIc injury. There is a great deal of subjectivity inherent in this classification system, yet it remains the most widely used because it is easy to remember.

2.3.6   Management of open fractures

All open fractures need to be operated on to remove as much contamination as soon as possible after injury. In the emergency department a culture swab should not be taken from the wound, and broad-spectrum antibiotics should be administered.

In the operating room, irrigation and debridement is the mainstay of treatment. However, this procedure is far more than a "washout" of the wound. Before surgery, the wound should be exposed and the limb washed with an antiseptic solution to remove any gross contamination. The limb is then formally prepared for surgery.

Debridement means the systematic removal of all necrotic or contaminated tissue. In general, it begins at the skin with a knife and all edges which are dusky or have capillary bleeding within the dermis are then removed. Also, any skin which cannot be adequately cleaned needs to be dissected. Next, any tissue in the subcutaneous layer which is contaminated or does not bleed when cut needs to be excised. Then, muscle and periosteum which is not viable should be excised. Muscle which is viable has four characteristics: color (red), consistency (does not pull apart when teased with forceps), contractility (muscle contraction when pinched lightly with forceps), and capacity to bleed. Again, any

muscle with gross contamination that cannot be otherwise cleaned should be removed. Finally, bone which has no soft-tissue attachments is considered dead and in most cases should be removed.

After debridement, which may be a time-consuming process, irrigation will wash away or dilute any remaining bacteria or small particles of necrotic debris. There is some debate about whether high-pressure lavage, low-pressure lavage, or bulb syringe should be used. The assistant should follow the surgeon's preferences. In general, high-pressure lavage is more effective in removing bacteria but at the cost of more tissue damage. Conversely, a bulb syringe may leave behind large amounts of debris but is tissue friendly. Regardless of which irrigation solution is used or which technique, the goal is to render a wound surgically clean when the procedure is complete.

Further culture samples may be taken after debridement and irrigation. Open fractures must generally be stabilized to allow both the fracture and the soft tissues to heal. This can be done using internal fixation, but in contaminated fractures or patients with multiple injuries the application of an external fixator is the preferred treatment.

2.3.7   Compartment syndrome

Compartment syndrome is an orthopaedic emergency. It is caused by an increase in pressure within a muscular compartment which exceeds the pressure within arterioles and capillaries. This change in pressure prevents the exchange of nutrients and waste products across vessel walls, causes muscle ischemia, and if untreated, leads to muscle necrosis and damage to nerves passing through the compartment. Compartment syndrome most commonly occurs in the forearm or lower leg after a fracture, but can happen after a severe soft-tissue injury or vascular injury alone. It can also be seen in the hand or foot after crush injuries and is occasionally seen in the upper arm and thigh following severe trauma.

Author   David Volgas

The diagnosis of compartment syndrome is primarily a clinical one. The main physical sign is pain out of all proportion to the injury, which is exaggerated by passive stretching of muscles in the compartment (usually achieved by flexion or extension of the fingers or toes). There may be associated alteration to sensation or paresthesia in the limb distal to the affected compartment. Pulses are generally palpable in the limb and are not a reliable guide to the diagnosis.

There are methods to quantitatively assess compartment pressures. These include prepackaged kits which are used with a compartment pressure monitor, the use of an arterial line monitor, or of a mercury manometer. There is some debate about which compartment pressure value to use to indicate a compartment syndrome, but any pressure of more than 30 mm Hg lower than the diastolic blood pressure is considered to be clear evidence of compartment syndrome.

The treatment of compartment syndrome is emergency surgical decompression of all compartments in the affected limb (four in the lower leg and two in the forearm). This is generally accomplished in the operating room, but may occasionally be done in the intensive care setting. The surgical technique involves making longitudinal incisions through the skin and muscle fascia directly over the compartment (Fig 2.3-4). These wounds are initially left open. Closure can be done later with skin grafts or delayed primary closure.

Anterolateral incision

Subcutaneous tibial border

Posteromedial incision

Anterial tibial vessels and peroneal nerve

Personeal vessels

Posterior tibial vessels and tibial nerve

a

- Anterior compartment
- Personeal compartment
- Deep posterior compartment
- Superficial posterior compartment
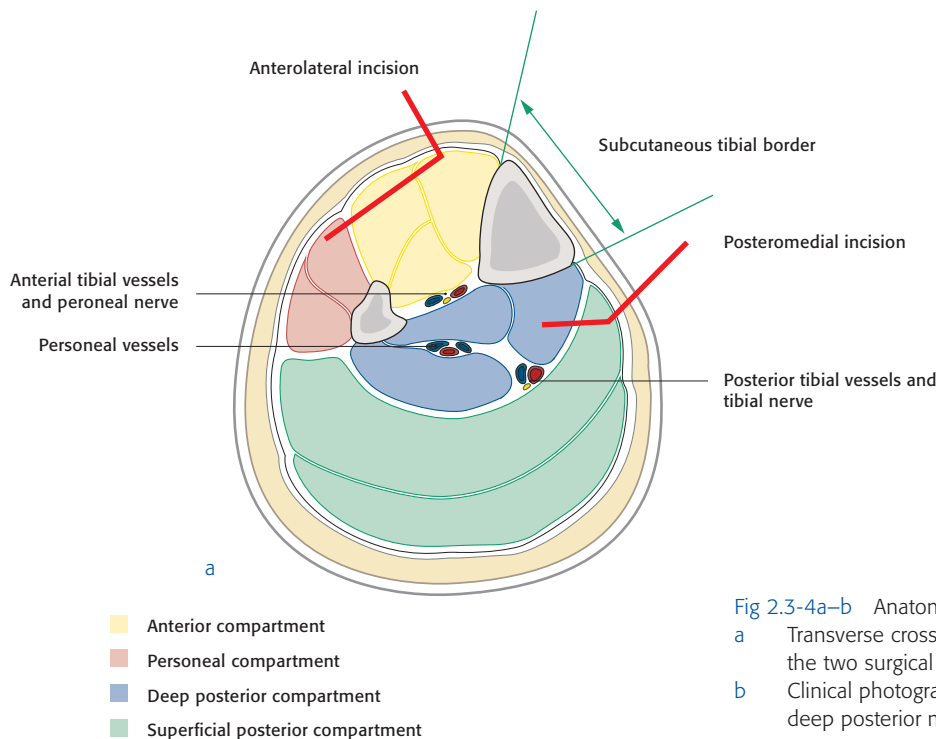
Fig 2.3-4a–b   Anatomy of the four compartments of the lower leg (cross-section).
a   Transverse cross-section of the lower leg showing four muscular compartments and the two surgical incisions necessary to decompress them.
b   Clinical photograph showing medial incision used to decompress superficial and deep posterior muscular compartments.

2.3.8 Conclusion

Good fracture surgery is more about taking extreme care of soft tissues than it is about achieving optimal fracture fixation. Fractures will heal provided the bone has not had its blood supply from the soft tissues damaged by the surgery, and careful handling of the soft tissues ensures quick wound healing without infection. Care of soft tissues is the key to good fracture management.

2.3.9 Further reading

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2.4   Instrumentation

2.4.1   Spectrum of stability   Piet de Boer

When a bone fractures there is always a disruption in the continuity of the bone. Complete fractures that are displaced also demonstrate instability. When the patient loads the injured limb, as for example putting weight on a fractured tibia, there is gross movement of the bone ends. This movement causes pain and may result in a delayed union or nonunion. If the instability remains uncontrolled it will almost certainly result in the fracture healing in a shortened or angulated position, such that function may not fully recover even after the bone has united. Instability may therefore cause pain, delayed or nonunion, and poor-end function due to malunion or an inability to mobilize the injured limb.

Treatment of a fracture always involves stabilization of the fracture. There is a range of stability that can be achieved with treatment, varying from gross movements on loading the fracture site to movements that can only be detected by specialized instruments. This is what is meant by the spectrum of stability. For practical use, however, surgeons define only two types of stability at a fracture site after treatment, absolute stability and relative stability.

Types of stability

Absolute stability means that when a bone is loaded with a physiological load, for example partial weight bearing with crutches, no detectable movement occurs at the fracture site. Relative stability means that there is a degree of controlled movement at the fracture site on physiological loading. Relative stability provides the amount of movement required to stimulate the natural healing process of callus formation but not so much as to involve a risk of nonunion. Both types of stability are sufficient for the patient to be able to mobilize the affected limb and adjacent joints without significant pain.

Absolute stability

The bone healing that occurs after a fracture has been fixed to achieve absolute stability is fundamentally different from the normal healing processes seen in fractures treated with relative stability. When absolute stability is obtained fractures heal by bone growing directly across the fracture site and no callus formation is seen (Fig 2.4-1). This type of healing is termed direct bone healing (sometimes called primary bone healing). Direct bone healing is a slow process which closely mimics the processes of remodeling seen following natural bone healing. Because it is slow, the fracture relies on the mechanical implant used to fix it for a much longer period than those fractures treated using a technique which stimulates the production of callus.
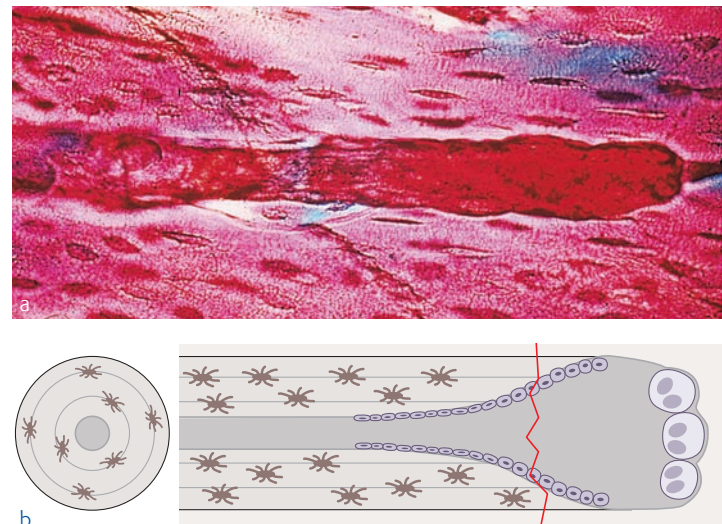
Fig 2.4-1a–b
a   Histological appearance of direct cortical bone healing. The areas of dead and damaged bone are replaced internally by Haversian remodeling. The fracture line has been graphically enhanced.
b   Diagram of Haversian remodeling. Osteoclast at the tip reabsorbed dead bone. Behind the tip osteoblasts lay down new bone to form an osteon.

For bone to be able to grow directly across the fracture site, it is essential that there is no movement between the fracture ends, and the gap between them must be small. To achieve this, the fracture must be anatomically reduced and the bone ends compressed together. Direct bone healing also requires a good blood supply to the bone so it is essential to minimize periosteal stripping and soft-tissue damage around the fractured bone. Excessive soft-tissue stripping at or around the fracture site results in islands of dead bone which do not unite, regardless of the stability given to them, until revascularization occurs.

Relative stability

Treatment which achieves relative stability leads to healing with callus. This is sometimes referred to as indirect or secondary bone healing. Callus formation requires a degree of controlled movement at the fracture site and, as with absolute stability techniques, preservation of blood supply is critical to fracture healing. Anatomical reduction is not required but in diaphyseal or metaphyseal fractures the correct length, axis, and rotation of the limb must be maintained or restored to allow normal function once fracture union has occurred. Callus formation is a faster process than direct bone healing. The fracture is dependent on the implant for stability for a shorter period than when absolute stability techniques are used.

2.4.1.1 How to achieve absolute stability

Absolute stability requires anatomical reduction, compression across the fracture site, and the preservation of blood supply.

Reduction technique: An open direct technique is usually required to obtain anatomical reduction. The fracture is exposed and reduced under direct vision. Restoration of length may be made using an ancillary aid, such as a femoral distractor or external fixator, but the final reduction is usually made using pointed reduction forceps or a similar bone clamp.

Surgical approach: A formal surgical approach is usually indicated. It is possible to achieve anatomical reduction of simple fractures using minimally invasive techniques and specialized reduction clamps, but in nonspecialized practice an open surgical approach is generally indicated.

Fixation techniques: The most common way of achieving compression at a fracture site is with the use of plates or screws. The lag screw is the standard working tool used to obtain absolute stability (Fig 2.4-2). Compression at the fracture site can either be
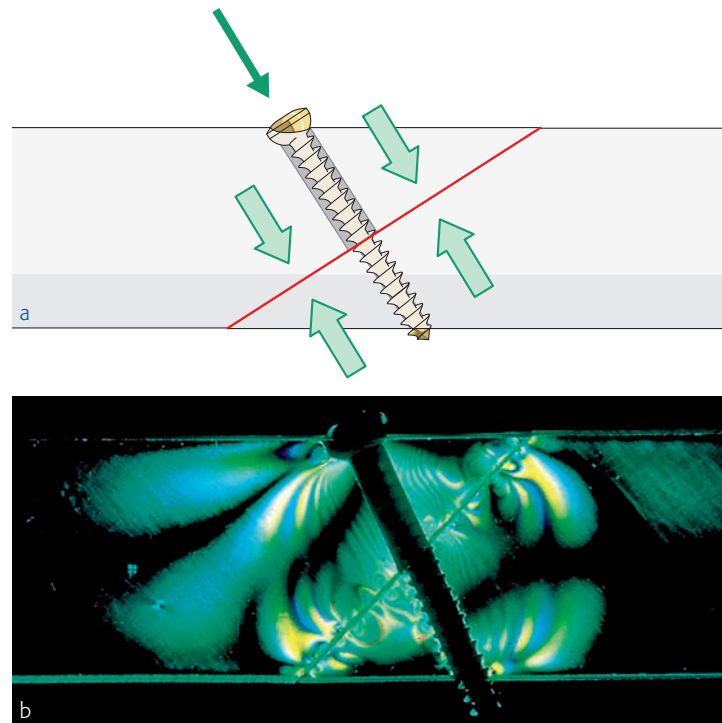
Fig 2.4-2a–b
a   A lag screw applied perpendicular to a fracture line provides the best form of absolute stability.
b   Areas of compression around a lag screw inserted across a fracture are illustrated in this photo-elastic material.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

obtained using the design of the screw, ie, the partially threaded cancellous bone screw, or by over drilling the near cortex—the classic cortical lag screw (see chapter 2.4.2). The insertion of lag screws necessarily involves some soft-tissue dissection and great care must be taken not to devitalize bone fragments with the instrumentation used for the insertion of the screw. A plate is normally required to reinforce lag screw fixation of a long bone, and in these circumstances is described as a protection (or neutralization) plate. A plate of identical design can also be used in a different way to obtain compression and achieve absolute stability (see chapter 2.4.3). Specialized ring external fixators can also be used to achieve absolute stability but this technique is usually reserved for nonunions and is rarely indicated in acute trauma.

All techniques used to achieve absolute stability carry a significant risk of devitalizing bone. A good, gentle surgical technique is therefore more critical in absolute stability than in relative stability techniques.

2.4.1.2   How to achieve relative stability

Relative stability can be obtained at a fracture site by various means.

Plaster of Paris: This is still the most commonly used means of obtaining relative stability. Plaster of Paris provides stability toward bending and twisting forces but cannot prevent fracture shortening, if the fracture pattern is such that shortening tends to occur. The foremost advantage of plaster of Paris is the preservation of the soft-tissue envelope around the fracture site. The disadvantage is that plaster immobilizes the joints above and below the fracture site preventing their mobilization.

Intramedullary fixation: This is a classic splinting technique which results in relative stability being achieved at the fracture site. Intramedullary nails preserve the soft tissues around the fracture site when an indirect reduction technique is used and the fracture site is not opened. X-ray imaging during surgery with an image intensifier is essential. Intramedullary nails provide excellent stability with regard to bending forces but do not provide any stability with regard to twisting forces or shortening unless locked. Locked nails provide excellent relative stability and are the implant of choice for diaphyseal fractures of the tibia and femur (Fig 2.4-3).
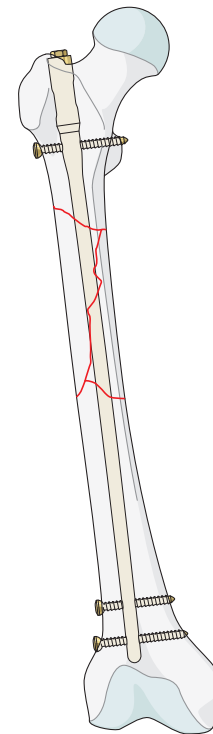
Fig 2.4-3   A locked intramedullary nail providing relative stability in a long-bone fracture.

External fixators: These also achieve relative stability. They can be constructed in various ways. Changing the number of pins, their site, size, and the number and position of the bars used to connect the pins can radically change the amount of stability given to any treated fracture site (Fig 2.4-4). External fixators preserve the soft-tissue envelope around the fracture site and are particularly useful when fractures are associated with extensive soft-tissue damage, ie, open fractures.

Plates and screws: These can also be used to achieve relative stability. The plate is applied to the reduced fracture and screws are inserted into the main bone fragments above and below the fracture site. No lag screws are used. An anatomical reduction is not necessary, but achieving the correct length, axis, and rotation of the bone is essential. Used in this way, the plate is known as a "bridging plate" (Fig 2.4-5).

If reduction can be obtained by indirect means, such as an external fixator, then an incision may be made above and below the fracture site, the plate is slid between the two incisions and fixed to the two main bone fragments with minimal disturbance of the soft tissues around the fracture. This technique is known as minimally invasive plate osteosynthesis (MIPO). The advantage of this technique is that it preserves the soft-tissue envelope around the fracture site. The disadvantage is that it is technically difficult to achieve and malunions are not uncommon.
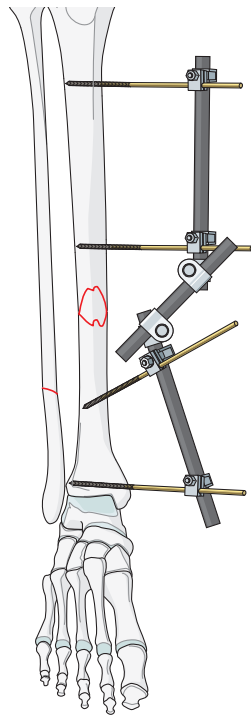
Fig 2.4-4   External fixator providing relative stability.
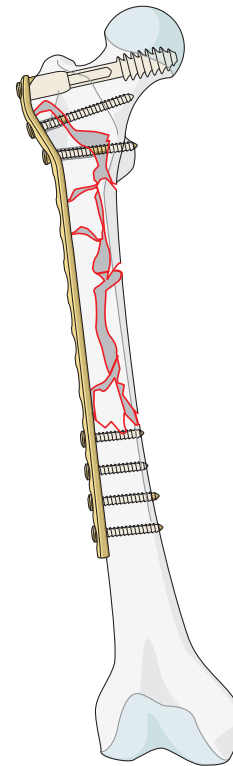
Fig 2.4-5   A plate applied as a bridging plate to provide relative stability.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

2.4.1.3   Locked internal fixators (LCPs fixed with locking head screws)

The most modern design of plates allows use of screws that lock into the plate, namely locking head screws. Once this occurs the plate screw unit becomes a single piece of metal. The locking compression plate (LCP) has screw holes for both locking head screws and conventional screws (Fig 2.4-6). Like other plate types, the LCP can be used to achieve absolute or relative stability depending on how it is applied. When an LCP is used to achieve absolute stability, a lag screw can be inserted either through the plate or independent from it to achieve compression at the anatomically reduced fracture site. The plate then functions as a protection plate. Conventional or locking head screws can be used in this mode depending on the quality of the bone. To act as a compression plate, the first screws inserted have to be conventional ones (see chapter 2.4.3). Subsequent screws used to reinforce the plate's initial grip on the bone can be conventional or locking again depending on the bone quality.

Fig 2.4-6   A locking compression plate has holes that may be used for conventional or locking head screws.

When an LCP is used to achieve relative stability, it is used as a bridging plate with conventional or locking head screws inserted into the two main fragments each side of a fracture, with minimal disruption to the soft tissues around the fracture. No lag screw is used. Locking head screws are particularly useful in osteoporotic bone and metaphyseal fractures.

Indications for absolute stability techniques

The key indication for the use of absolute stability techniques in the 21st century is in intraarticular fractures. Good joint function can only be obtained in intraarticular injuries if the articular surface of the joint is restored anatomically and the fracture fixed using an absolute stability technique. Only in this way can early active movements be obtained and the nutrition to the articular cartilage preserved during the healing phase.

Absolute stability is also indicated in fractures of the forearm, when any degree of malunion will result in loss of forearm rotation. These therefore require anatomical reduction. Absolute stability techniques are more likely to be used if the fracture patterns are simple and are also indicated in the treatment of nonunion and in osteotomies.

The major contraindication to the use of absolute stability techniques is the treatment of multifragmentary fractures. The main danger in applying absolute stability is devitalization of the bone while achieving reduction, thereby delaying or abolishing healing. The more fragments there are in a particular fracture the more lag screws need to be inserted to achieve absolute stability and the greater the chances are that the bone will be devitalized. Multifragmentary diaphyseal fractures should not be treated with absolute stability techniques.

Indications for relative stability techniques

The best indication for relative stability is the treatment of multifragmentary diaphyseal and metaphyseal fractures. If a good functional reduction is obtained, ie, correct length, axis, and

rotation, rapid union occurs together with the restoration of excellent function.

Most diaphyseal fractures in the tibia and femur are treated with relative stability techniques using intramedullary nailing even if they have a simple fracture pattern.

Relative stability is contraindicated in intraarticular fractures and should not be used in the treatment of delayed union or nonunion.

2.4.1.4   Conclusion

Absolute stability is achieved when there is no movement at the fracture site on physiological loading. Healing occurs by bone growing directly across the fracture site. It requires the preservation of blood supply, an anatomical reduction, and interfragmentary compression. Absolute stability is indicated in the management of intraarticular fractures and in simple diaphyseal fractures apart from the tibia and femur.

Relative stability implies controlled movement at a fracture site, sufficient to generate callus formation while allowing painless mobilization of the limb. It requires the preservation of blood supply, a functional reduction, and the creation of controlled movement at the fracture site. Relative stability is indicated in the management of nonarticular fractures, especially multifragmentary fractures of the metaphysis and diaphysis.

2.4.2   Screw techniques   Daniel Saris

A screw is a mechanical device that converts rotation into linear movement, as you rotate the screw clockwise the tip of the screw advances. Everyday examples include the propeller on an airplane or boat, and a corkscrew.

In fracture surgery screws are used to achieve absolute stability either by acting as a lag screw or by being an integral component of a plate used as a compression plate. Screws can also be used to help achieve relative stability by holding a bridging plate in place with either conventional or locking head screws. In the modified form of a Schanz screw, a major component of an external fixator, screws can also be used to achieve relative stability.

In this section the form and design of conventional screws is explained. The application of interfragmentary compression using a lag screw, the concept of the position screw, some technical aspects of screw insertion, and correct use of instruments are described.

2.4.2.1   Screw names

Screws are named after different attributes including:

- Size (eg, 3.5 mm or 4.5 mm), by convention the size usually refers to the thread diameter
- Design (eg, locking head, cannulated)
- Function (eg, lag, position)
- Characteristics (eg, self-tapping, self-drilling)
- Application site (eg, cortical, cancellous or bicortical)

These terms are sometimes mixed, for example, a screw might be referred to as a 4.5 mm self-tapping cortex screw. Since the introduction of locking head screws, all other screws are now referred to as "conventional."

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

Screw basic design

A standard bone screw is made up of a head, core, thread, and screw tip. The thread which is wound around the solid core grips the bone and converts the rotatory movement of the screwdriver into linear movement as the screw advances. Eventually the screw head engages in the bone or plate and with further advancement compression is applied.

Core and thread: Each screw consists of a central solid core or shaft. Around this is the thread which provides contact with the bone (Fig 2.4-7). The distance between successive turns of the thread is called the thread pitch. The thread design and pitch varies with the screw type and function but is intended to maximize contact with the bone into which it is fixed. The pullout strength of the screw is determined by the volume and strength of the bone that is gripped within the thread, and this in turn determines how

solidly the screw can be fixed in the bone. The thread can extend the whole length of the screw (fully threaded) or only partly from the tip leaving a section of bare shaft (partially threaded).

Head: The head has two main functions. First, it provides a coupling between the screw and the screwdriver—this is either hexagonal or star shaped in most bone screws (Fig 2.4-8). Second, it exerts compression on the underlying bone or plate as the screw advances. In locking head screws (LHS) the head is threaded to engage with the threaded hole in the plate.

Conventional bone screw heads are hemispherical, allowing the screw to be angled in different directions while maintaining a constant contact with the surface of either the bone or the plate hole. The shape also enables the screw to glide down the slope of the oval hole of a compression plate to facilitate dynamic compression between two bone segments (see chapter 2.4.3).
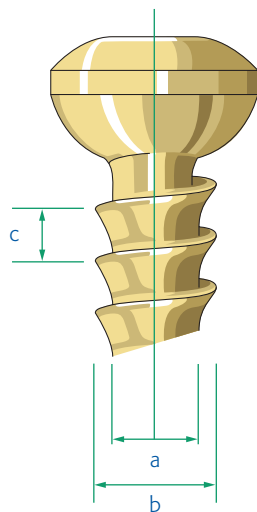
Fig 2.4-7a–c   A screw illustrating:
a   Core diameter.
b   Thread diameter.
c   Pitch.
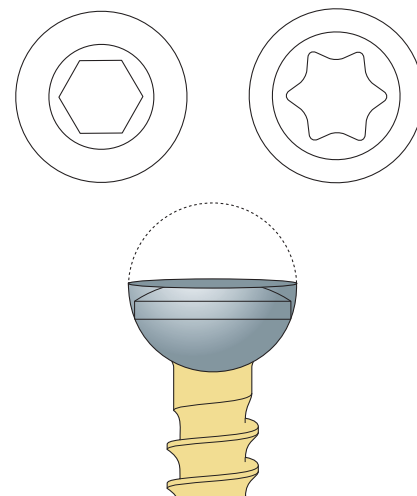
Fig 2.4-8   Conventional screws have a hemispherical head and a hexagonal (1) or star-shaped (2) recess for coupling to the appropriate screwdriver.

Screw tip: The screw tip has the first contact with the bone. When the screw tip is rounded, the thread needs to be precut in the bone with a tap. Self-tapping screws have to cut their own thread and have flutes cut into the tip to carry away the bone removed by the tapping process (Fig 2.4-9). Some types of external fixator Schanz screws and some LHS have self-drilling and self-tapping tips.

2.4.2.2 Screw profile and function

The main difference between cortex and cancellous bone screws lies in the thread profile, which has consequences for the technical aspects of their insertion.

Cortex screws

Cortex screws are designed for use in hard cortical bone and are usually fully threaded. Their thread is designed to closely engage the thread cut in the bone, maximizing contact between the two (Fig 2.4-10a). The thread can be either precut with a tap or the screw can be self-tapping. Pull-out strength is dependent on the thickness and quality of the cortical bone, and is significantly reduced in osteoporosis.

Cancellous bone screws

Cancellous bone screws are mainly used in metaphyseal bone around joints. They come both fully and partially threaded and have a much wider thread which is designed to push the much less solid cancellous bone into the area between the screw threads as they advance, creating a solid wall of compacted bone in which to grip. Their action is similar to that of a snow plough (Fig 2.4-10b–c). The tap should only be used in the outer cortex of the bone and is not required at all in poor-quality bone. Like cortex screws their pull-out strength depends on the quality of the bone into which they are inserted. In osteoporotic bone it is easy to over tighten them, stripping the thread from the bone, and leaving them unable to provide any compression at all. Achieving adequate compression also depends on the screw head having
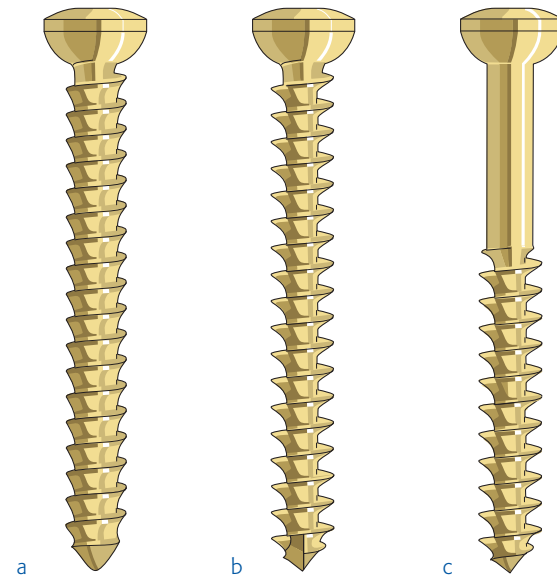
Fig 2.4-10a–c
a   A fully threaded cortex screw.
b   A fully threaded cancellous bone screw.
c   A partially threaded cancellous bone screw.

Fig 2.4.2-9a–b
a   Conventional screw tip.
b   Self-tapping screw tip.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

good purchase on the surface of the bone. In poor-quality bone, cancellous bone screw compression can be augmented by using a washer. This increases the contact area of the head with the bone, which helps to prevent the head sinking into the softer metaphyseal cortex.

Locking head screws

Locking head screws (LHS) have shafts with a thicker core and narrower threads with a finer pitch. All LHS are self-tapping with cutting flutes at the tip (Fig 2.4-11). These differences in design reflect the fact that because the heads are locked into the plate, pull-out strength is less important than resistance to bending, and the fine threads are more for advancing the screw into the bone than resisting pull out. The head has a thread which appears to be twice the pitch of that of the shaft but is in fact two equally spaced parallel threads of the same pitch as the shaft. This doubles the contact area between the screw head and plate and improves the strength of this link.

Cannulated screws

Cannulated screws have a hollow shaft and are designed to be inserted over a preplaced guide wire of appropriate size (Fig 2.4-12). The guide wire can be inserted into the exact spot required under image intensifier control and can help hold a fracture reduced during screw insertion, ensuring accurate screw placement. Most cannulated screws are designed for use as partially threaded cancellous bone screws, and are inserted to act as lag screws.

Technique for insertion varies with different types of cannulated screw; some are designed to be inserted without predrilling or tapping. If drilling is required, it is important not to advance too close to the tip of the guide wire, as the guide wire will then fall out when the drill bit is removed. Many of the guide wires have threaded tips to get a good grip in the far cortex and reduce the chance of their loosening. Like for conventional cancellous bone screws, the tap should only be used in the outer cortical bone.

2.4.2.3   Screw insertion

Drilling

The technical sequence required to insert a screw correctly depends on the exact nature of the screw, however there are some basic guidelines.

For a plate-holding screw a pilot hole is drilled in the required position with a drill bit equal to the core diameter of the screw, protected by a drill guide. The drill guide is important both to protect the soft tissues and to control the drill bit to ensure accurate drilling. Drill bits are designed to run forward at full speed, the drill bit should not be reversed when being pulled out. Blunt drill bits generate a lot of heat and can cause heat necrosis and subsequent screw loosening. Therefore, it is crucial to use sharp drill bits and to keep all instruments clean during the procedure. In particular the drill bit flutes must be kept free of any debris to ensure the drill bit functions correctly.

Fig 2.4-11   A locking head screw with self-tapping tip.

Fig 2.4-12   A cannulated self-tapping cancellous bone screw.

Measuring

The screw length is measured before tapping as the depth gauge may damage the delicate threads if the hole had already been tapped. When the measured screw length does not match the lengths in the available screw selection, a screw one size longer than measured must be inserted so that the screw tip passes through the far cortex ensuring maximum bone screw thread contact. When using self-tapping screws, 1 mm for small fragment and 2 mm for large fragment screws should be added to the measured screw length since the fluted tap slots in the screw tip do not provide adequate bone fixation, and removal of the screw can be more troublesome if the fluted slots become filled with ingrown cortical bone. This is less likely to occur when the screw tip protrudes through the bone on the far cortex.

Tapping

Tapping should only be done by hand, using the appropriate tap and the protection sleeve. The sleeve not only protects the adjacent soft tissues but also helps ensure that an even spiral tap is cut. Without the sleeve the tap can rock from side to side creating an uneven thread which results in lower pull-out strength. The full length of the hole requires tapping in cortical bone, but when a cancellous bone screw is used only the outer cortex is tapped. When tapping hard bone, the tap should be reversed half a turn every one or two turns to clear the tap thread of bone debris. Power tapping is not recommended. In hard bone a powered tap quickly becomes hot enough to cause bone necrosis and can even break, leaving the broken end in the thread hole, while in soft bone it is difficult to detect when the tap has passed through the far cortex. There are many reports of damage to nerves and blood vessels by taps inserted too far under power.

Insertion

Before insertion, the length and type of the screw should always be confirmed with the surgeon. It is important not to over tighten it and strip the thread in the bone. Research has shown that with the correct technique and experience, the surgeon should be capable of inserting the screw to within 85% of maximal fixation strength, which is more than is needed for proper pull-out strength, and thus optimal fracture fixation.

Screw function

Screws may be used in many different ways. These are outlined in Tab 2.4-1. The common screw functions are described in more detail below.

Plate screw

A conventional screw is placed through a hole in the plate to compress it against the underlying bone. In the diaphysis this is normally a bicortical cortical screw. The insertion technique is described above.

Lag screw

A lag screw is the most effective way to apply compression between two fracture fragments. This requires the screw to only engage the far cortex of the two bone fragments, so the near fragment, through which the screw passes but the screw threads do not engage, is compressed between the screw head and the far fragment. For optimum compression a lag screw should cross a fracture site at 90º to the fracture.

In cancellous bone, lag screw fixation is achieved by using a partially threaded screw inserted so that all the threads cross beyond the fracture site. As the screw is tightened, compression is applied.

In cortical bone the following sequence is used: First, a gliding hole is drilled in the near cortex (Fig 2.4-13a). This is the same diameter as or slightly larger than the thread diameter of the screw to be used, so the screw thread does not engage the bone. A guide sleeve is then inserted into the gliding hole and a pilot hole is drilled in the far cortex (Fig 2.4-13b). The bone is countersunk to increase the area of contact between the screw head and the bone and reduce the risk of a stress riser and fracture as the screw is tightened. The depth is measured and the pilot hole tapped

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

(Fig 2.4-13c). A screw of appropriate size is inserted and tightened (Fig 2.4-13d).

A table of the appropriate size pilot and gliding holes for different screw sizes is shown (Tab 2.4-1).

Position screw

A position screw is placed across two separate segments of bone with a tapped pilot hole in both segments. This means that the screw maintains the relative position of the two fragments once they have both been engaged, and there is no compression exerted by the screw across the fracture site.

2.4.2.4   Conclusion

The screw is an essential tool as part of the many options for fracture fixation. Both small and large fragment screws can be used for compression of fracture fragments and for plate fixation. It is important to define the function and position of each screw as part of a preoperative planning for each specific fracture. Only then can the surgical team prepare correct sets and instruments and predefine the steps for the individual patient preparation, positioning, and surgical approach.
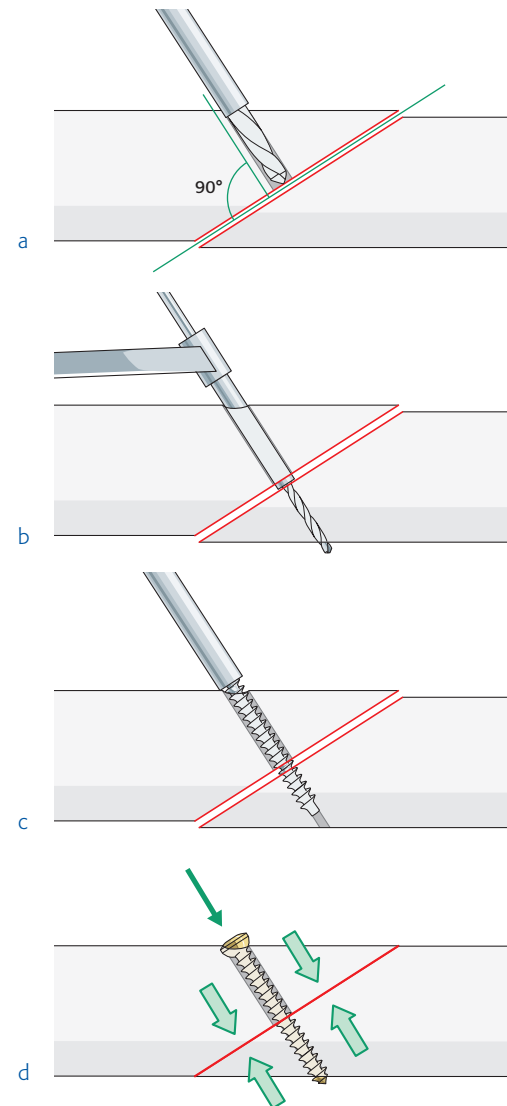
Fig 2.4-13a–d   A fully threaded 4.5 mm cortex screw inserted as a lag screw.
a   A 4.5 mm gliding hole is drilled 90° to the fracture line.
b   Using a drill guide, a 3.2 mm pilot hole is drilled.
c   A 4.5 mm tap is used to cut the thread in the pilot hole.
d   A 4.5 mm cortex screw is inserted and compression is achieved.

Screw type	Cortex screw	Cortex screw	Cancellous bone screw, partial thread	Cancellous bone screw	Cortex screw	Cancellous bone screw, short thread	Cancellous bone screw, long thread	Cancellous bone screw, full thread
Screw size, mm	2.7	3.5	4.0	4.0	4.5	6.5	6.5	6.5

Drill bit for gliding hole, mm	2.7	3.5	—	—	4.5	(4.5)	(4.5)	—
Drill bit for pilot hole, mm	2.0	2.5	2.5	2.5	3.2	3.2	3.2	3.2
Tap size, mm	2.7	3.5	4.0	4.0	4.5	6.5	6.5	6.5

Tab 2.4-1 Conventional screws—drill bits taps.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

2.4.3   Plates and plate techniques   David J Hak

Plates are multifunctional implants, used for the internal fixation of many fractures. They are manufactured in varying shapes and sizes for use throughout the body.

Plates are often described by their design or catalogue name, such as one-third tubular plate, DCP (dynamic compression plate), LC-DCP (limited-contact dynamic compression plate), or LCP (locking compression plate) (Fig 2.4-14).

Plates may also be described by their mode of use or function. The function that a plate performs is determined by the surgeon as part of the planning process before surgery, and this depends on how the plate is applied to the fracture. This means that even though a plate may be named a dynamic compression plate, the technique of application chosen by the surgeon may make it functions in a variety of ways, ie, as a protection or buttress plate.

The modes in which a plate may be used are compression, protection (also called neutralization), buttress, and tension band, all of which provide or protect absolutely stable fixation of the fracture, and allow the fracture to unite by direct healing without callus. The use of plates in bridging mode, which is a form of relative stability, is detailed in chapter 4.6.

In this chapter different uses of plates and their function are described.

2.4.3.1   Evolution of plate design

Plates (with the exception of locking plates) provide stability because the screws with which they are fixed compress the plate firmly to the bone, generating a frictional force between the plate and the bone. This force damages the periosteal blood supply under the plate, and this in turn initially gives rise to bone necrosis immediately beneath the plate. Then with time localized osteoporosis
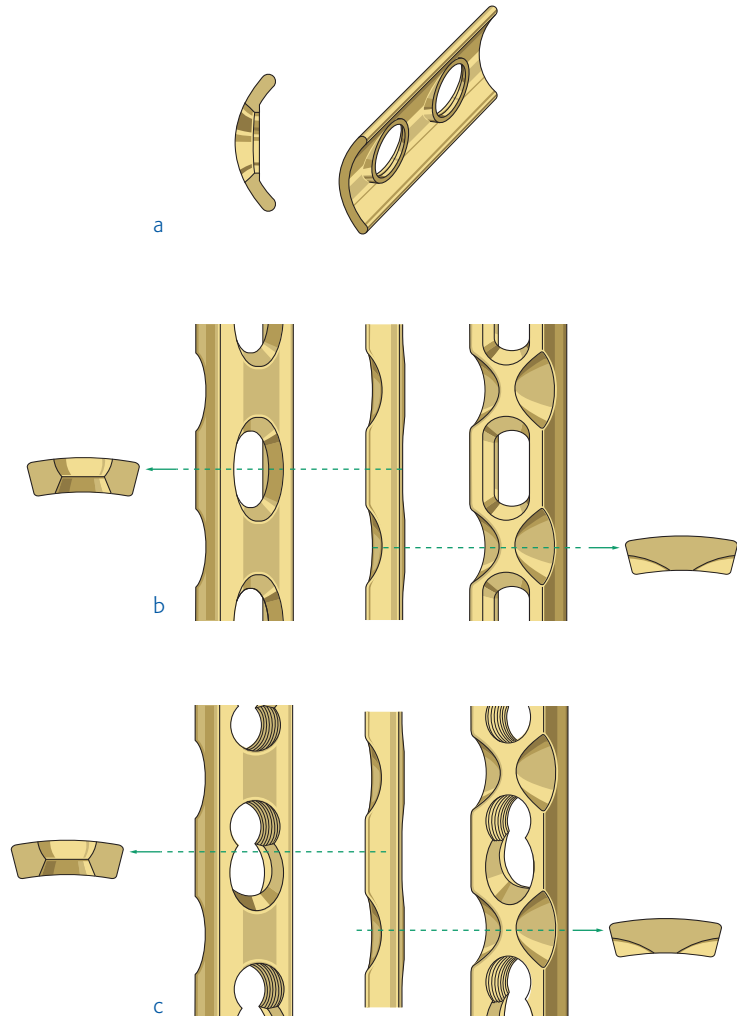
Fig 2.4-14a–c   Commonly used plates.
a   One-third tubular plate.
b   Limited-contact dynamic compression plate.
c   Locking compression plate.

occurs, as the dead bone is gradually reabsorbed and replaced. The degree of necrosis and subsequent osteoporosis depends on the footprint of the plate on the underlying bone. Traditional DCPs with their flat surfaces cause more periosteal damage and subsequent localized osteoporosis than the LC-DCP with its scalloped undersurface that reduces the plate footprint on the bone (Fig 2.4-15).

Locking plates use screws that have threads on the screw head which engage the threads in the plate holes, creating a fixed angle implant (see chapter 4.6). These plates can stand off the bone completely, thus further reducing damage to the underlying blood supply of the bone. Locking plates offer mechanical advantages in severely osteoporotic bone and in distal or proximal fractures where only a limited number of screws can be placed in the short fracture fragment. The LCP has a combination hole which allows for conventional screw or locking head screw fixation.
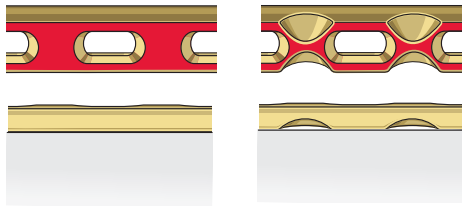
Fig 2.4-15   The undersurface of a DCP and LC-DCP showing the reduction in "footprint" on the bone.

In some circumstances the surgeon may choose to apply a plate across a fracture using a minimally invasive technique. This approach may reduce soft-tissue damage at the fracture site and preserve blood supply to the bone fragments. Special precontoured plates are now available for use in specific anatomical locations, and can facilitate this type of surgery. Even in these circumstances the mode of use of the plate, and thus the degree of stability at the fracture site, is still determined by the surgeon.

2.4.3.2   Different plate functions
Compression mode of plate/function
A plate functions in compression mode when it is applied in a manner that produces compression at the fracture site. This mode is generally used when fixing a simple two-part transverse or oblique fracture in a long bone. Compression can be achieved using an articulated tension device attached to the plate and bone (Fig 2.4-16), or by inserting a screw eccentrically within the specially designed hole of the DCP, LC-DCP, or LCP.

To apply a plate in compression, the plate is fixed to one side of the bone with a screw placed centrally in the plate hole (neutral position). On the other side of the fracture, a hole is drilled eccentrically through the plate hole away from the side of the fracture. As the screw is inserted, the screw head contacts the slope of the plate hole and as the screw is tightened the fracture is compressed. This occurs because in order for the screw to sit fully in the plate hole, the attached bone segment must be pushed toward the fracture (Fig 2.4-17).

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner
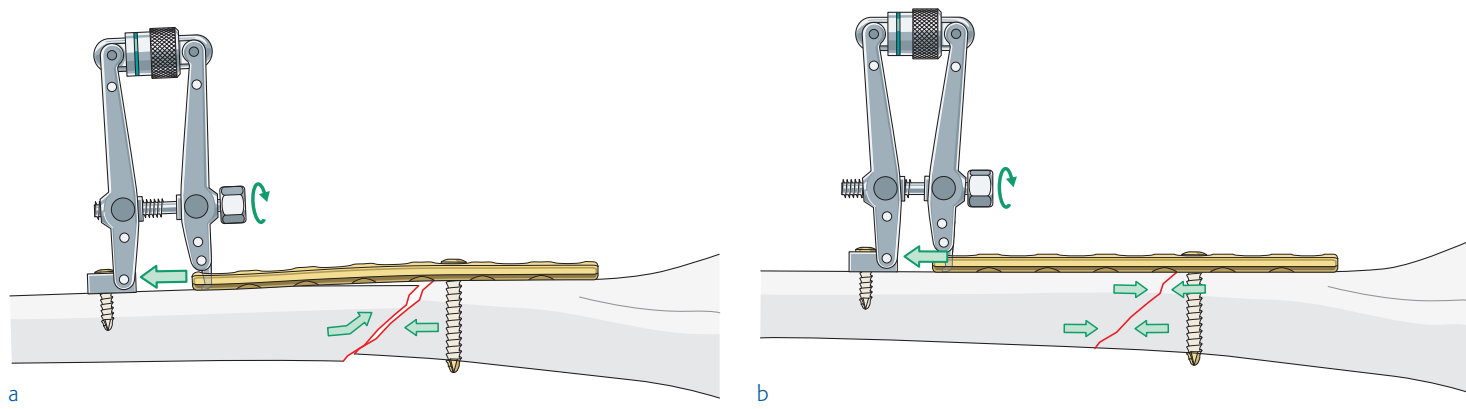
Fig 2.4-16a–b   Use of an articulated tensioning device to achieve interfragmentary compression.
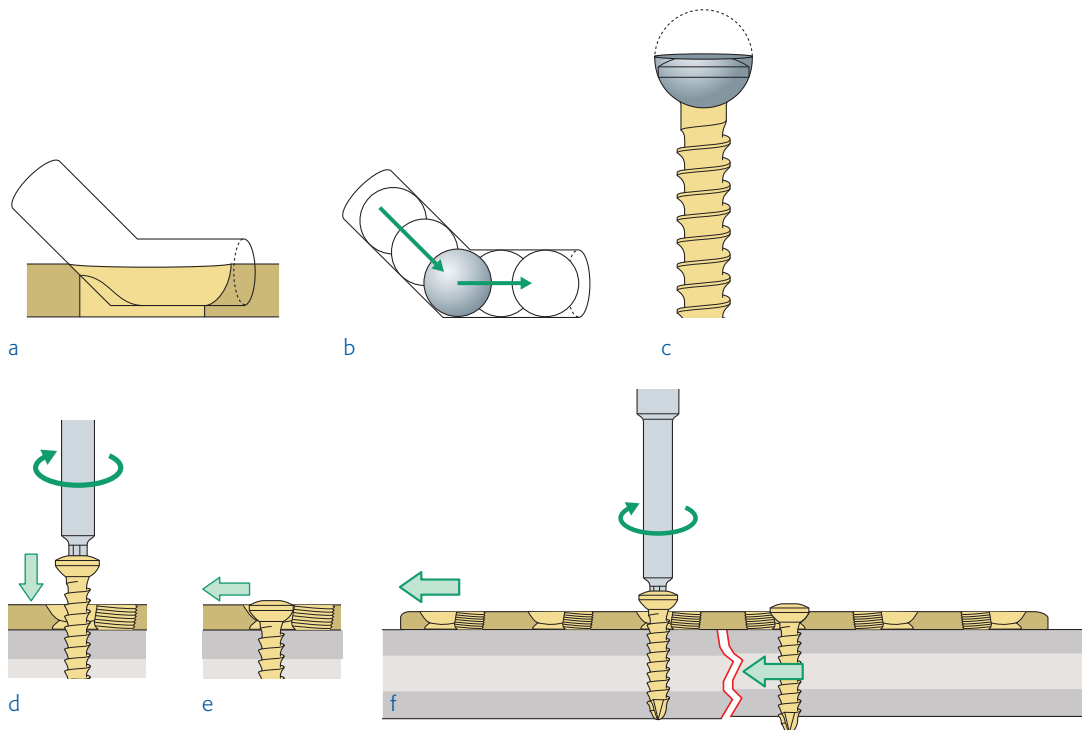
Fig 2.4-17a–f   Compression mode illustrated with an LCP:
a   The holes on the plate are sloped at one end.
b–c   The hemispherical head of the screw slides down the slope like a ball as the screw is tightened.
d–e   The screw and plate therefore move relative to each other.
f   This results in compression at the fracture site.

To place an eccentric drill hole with an LC-DCP, the yellow drill guide is used with the arrow directed toward the fracture (Fig 2.4-18). For the LCP implant, a spring-loaded universal drill guide must be used. It must be positioned eccentrically away from the site of the fracture in the non-threaded portion of the hole, without downward pressure on the spring (Fig 2.4-19).

Once the compression screws have been inserted, the further screws are placed through the plate holes in the neutral position to reinforce the plate's grip on the bone. If an LCP is used and the bone quality is poor, locking head screws can be used for this reinforcing function but they cannot be used to apply compression.

As a rule, when using conventional screws, a plate should be held by a minimum of six cortices on each side of the fracture (ie, three screws each side passing through both cortices). In larger or osteoporotic bones this may be insufficient, and there may be situations in which anatomy makes this impossible.

Protection mode of plate function

A lag screw is generally preferred for the fixation of an oblique or spiral fracture, as it generates the greatest compressive force across a fracture (see chapter 4.1). However, the fracture site is still subjected to forces of bending, shear, and rotation in other planes, which the lag screw resists poorly. A protection (or neutralization)

Fig 2.4-18a–b   Compression mode illustrated with an LC-DCP:
a   Using the green drill sleeve with the arrow pointing toward the fracture, positions the screw in the center of the plate hole.
b   Using the yellow drill sleeve with the arrow pointing toward the fracture, positions the screw eccentrically in the plate hole.
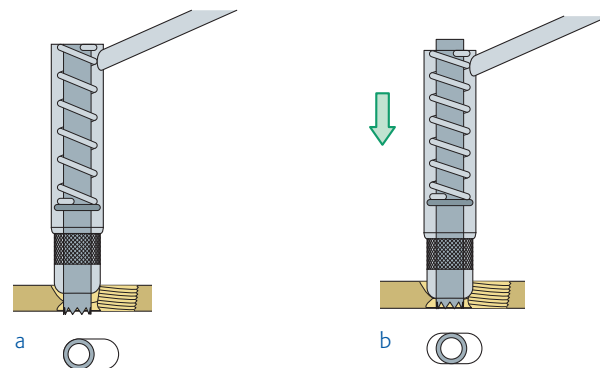
Fig 2.4-19a–b   Compression mode illustrated with an LCP:
a   A universal drill sleeve used without applying pressure places a screw eccentrically in order to achieve fracture-site compression.
b   By pressing the sleeve down into the hole the screw will be placed in a neutral position.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

plate is used to protect the lag screw fixation from these forces which can lead to lag screw failure (Fig 2.4-20). If the protection plate is fixed with conventional screws, it is important that it is accurately contoured to the bone; otherwise the tension generated at the fracture by the tightening down of an inaccurately contoured plate can cause the lag screw fixation to fail. This is not a problem if locking head screws are used, as the plate can be fixed standing off the bone.

Buttress mode of plate function

A plate functions in a buttress mode when it applies a force perpendicular to the flat surface of the plate. This is most commonly used in fractures around joints, such as a split fracture of the tibial plateau. When the plate is undercontoured, a compressive force is applied to the fracture as the plate is secured to the bone (Fig 2.4-21). Even in the absence of any screws in the fracture fragment, a properly positioned buttress plate will resist axial displacement of an accurately reduced fracture. However, in

practice additional lag screws across the fracture are commonly placed either through or adjacent to the plate.

Tension band mode of plate function

The tension band mode of plate function is presented in chapter 2.4.4. When applied to the tension side of an eccentrically loaded bone, the distractive forces on the tension side of the bone are taken up by the plate, allowing loading to provide a compressive force at the opposite cortex.

Bridging mode of plate function

Bridge plating is a method of achieving relative stability (see chapter 4.6), and it may be desirable in multifragmentary diaphyseal fractures. The plate is anchored to the bone outside of the zone of injury, avoiding any further soft-tissue injury or devascularization at the fracture site. It is important to obtain accurate length, rotation, and axial alignment before securing the plate.

Fig 2.4-20   A protection plate preventing a lag screw from bending, shear, and rotational forces.
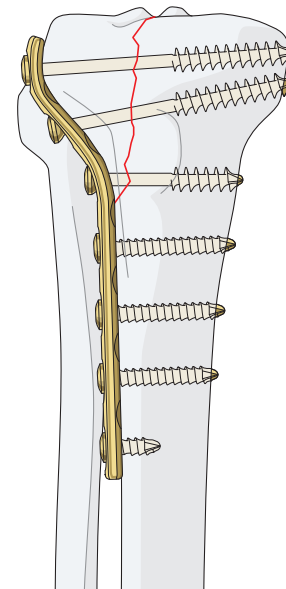
Fig 2.4-21   A contoured plate applied in buttress mode.

2.4.3.3 Compression plating

Plate prebending

When a flat plate is applied in compression mode, the greatest compressive force is produced on the cortex immediately under the plate; while little or no compression may occur at the opposite cortex (Fig 2.4-22). To compensate for this, the plate should be prebent (or prestressed). This causes bone contact to occur first at the far cortex when compression is initiated. The compressive force is then distributed evenly across the whole fracture as the compression is increased and the plate straightened out (Fig 2.4-23).
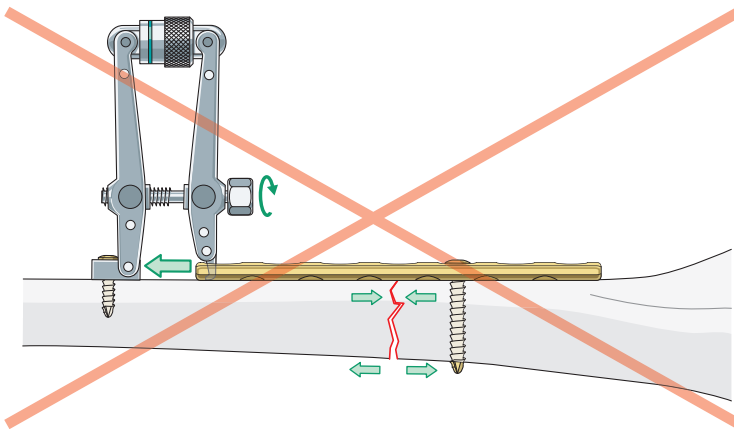
Fig 2.4-22   Compression applied to a flat plate on a straight bone will cause a transverse fracture to open opposite the plate.
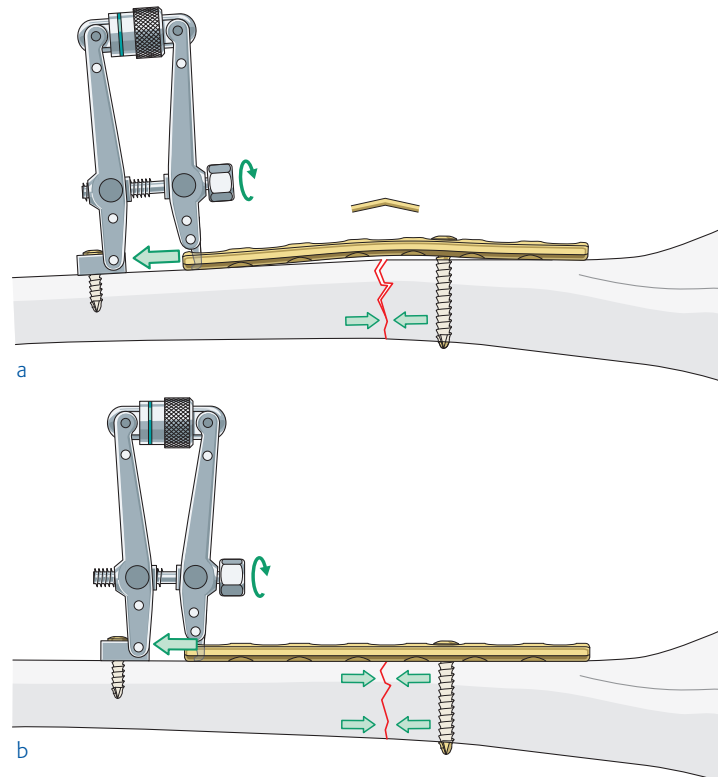
Fig 2.4-23a–b
a   When a plate is slightly prebent before application, fracture contact and compression occurs first at the opposite cortex.
b   Further tension on the plate will produce equal compression across the entire fracture line.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

Applying a plate to an oblique fracture

While lag screws are generally preferred for oblique fractures, these can sometimes be combined with compression plates to maximize compression at the fracture site. When applying a plate in compression mode to an oblique fracture, it is important to fix down the plate in such a way that it creates an axilla into which the acute angle of the fracture can be reduced (Fig 2.4-24a).

Compression can then be applied using a compression screw to force the acute angle of the fracture into the axilla.

Additional compression at right angles to the oblique fracture can finally be provided by inserting a lag screw through the plate and directed across the oblique fracture (Fig 2.4-24b). Planning such fixation in advance is important, as the lag screw requires precise placement and the hole through which it is placed must be accurately positioned.

If the plate is fixed to the wrong side of an oblique fracture, displacement can occur along the plane of the fracture with compression (Fig 2.4-24c).
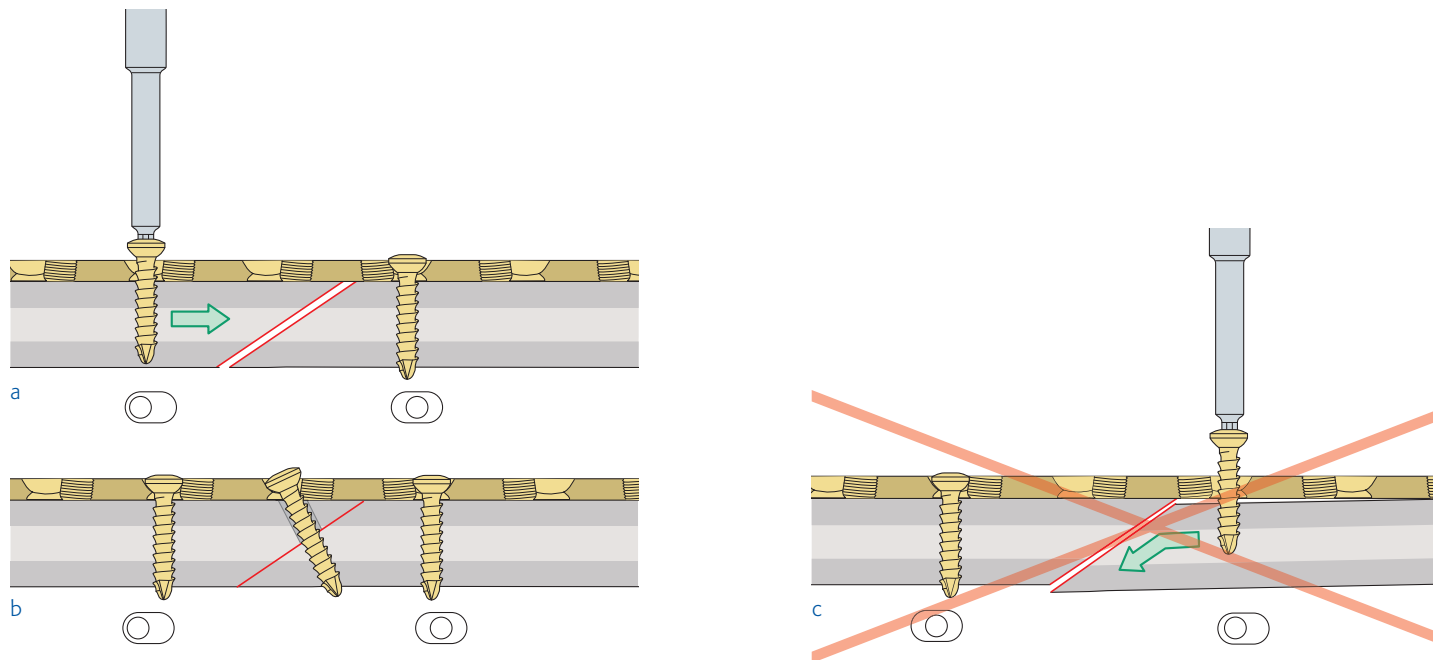
Fig 2.4-24a–c
a   In oblique fractures, the plate must be applied in such a way that the free fragment
     locks in to the axilla when compression is applied.
b   Compression can be increased by insertion of a lag screw through the plate.
c   The incorrect side of the plate has been anchored. Compression produces
     malreduction as the free fragment displaces along the fracture line.

2.4.3.4 Plate contouring

In traditional nonlocked plate fixation, the plate frequently needs to be bent so that its contour matches that of the bone. This may be achieved using various hand-held "bending irons" or bending pliers (Fig 2.4-25). A malleable aluminum template may be placed against the bone, serving as a template for plate bending (Fig 2.4-26). This avoids having to maneuver the plate in and out of the surgical site to check the conformity to the bone. Repeated bending back and forth should be avoided as this weakens the plate.

Reconstruction plates are characterized by notches between the plate holes which allow them to be bent or contoured in multiple planes (Fig 2.4-27). These plates are commonly used for fractures in areas where the bone has a complex 3-D shape, such as acetabular and distal humeral fractures.

2.4.3.5 Conclusion

Plates can be used to provide absolute stability used in compression, protection, buttress, or tension band mode, or relative stability when used as a buttress plate.

It is the surgeon who determines the function of a plate as part of the fracture-planning process.
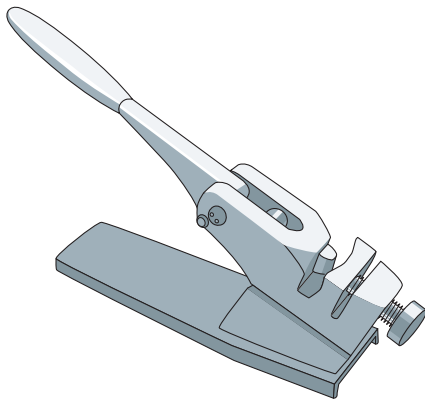
Fig 2.4-25 Plate-bending press.

a

b
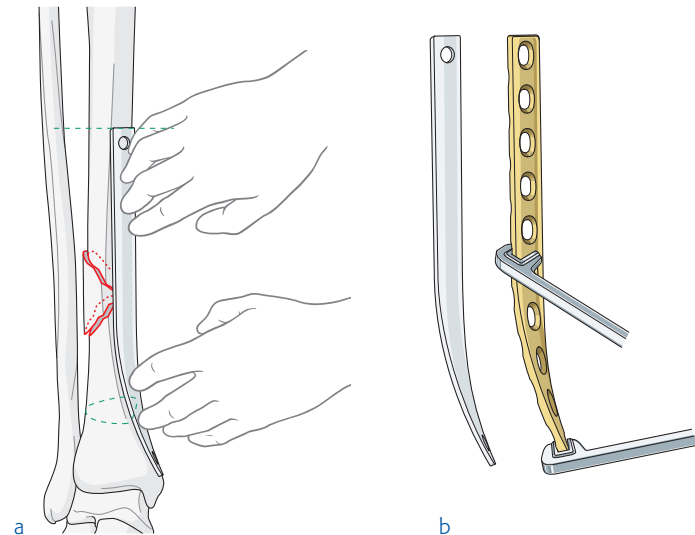
Fig 2.4-26a–b
a   A malleable template is molded against the bone.
b   Bending irons are used to contour the plate to match the template.

Authors Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

2.4.4 Tension band techniques Matthew Porteous

Using the tension band principle to achieve absolute stability is a concept that may be difficult to understand.

The principle is based on the fact that any structure that is loaded asymmetrically has some areas within it under tension and others under compression. Imagine an elephant on each end of a child's seesaw; the beam will break at the pivot. Intuition tells us that the fracture will start on the upper surface of the beam. This is the part that is under the most tension (Fig 2.4-28). Wood and steel (like bone) are weaker in tension than in compression, so this is where the point of failure occurs. We use exactly the same principle
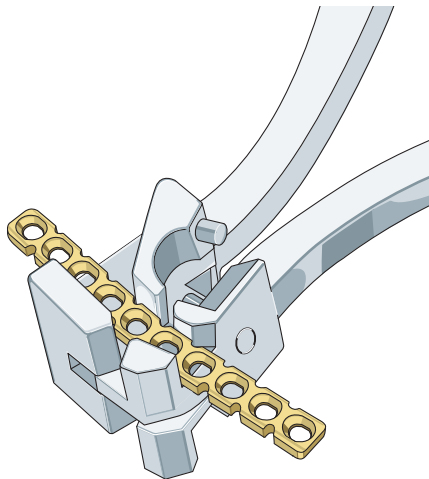
Fig 2.4-27 A reconstruction plate is contoured with special bending pliers.

a

b
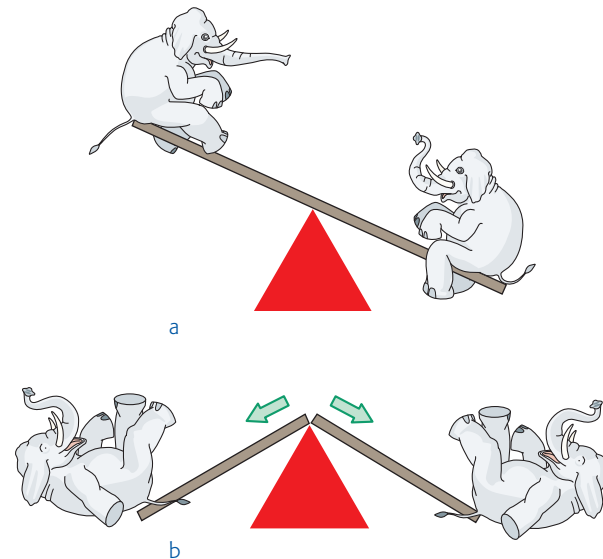
Fig 2.4-28a–b With excessive load failure of a beam occurs in tension.

when trying to break a dry stick. We bend the stick, creating tension on the convex surface and compression on the concave surface (Fig 2.4-29). Failure starts on the tension surface and travels rapidly through the stick, from there to complete the fracture.

The same dynamics may occur if weight is placed on the top of a solid column. If the weight is placed centrally, the whole column is loaded in compression with the load equally distributed throughout the column. However, if the load is placed off to one side (asymmetrically), the side nearest the weights remains in compression but the opposite surface is under the most tension. While in the middle part of the column there is an area that is neither under tension nor compression (Fig 2.4-30).

2.4.4.1 Tension band as a plate

A similar situation arises in the human femur, which is loaded eccentrically because of the offset of the femoral head and neck to the long access of the bone. This means the lateral side of the bone is under tension and the medial side is under compression when the patient walks (Fig 2.4-31a). In a simple transverse fracture of the femur, the failure starts on the lateral side because the collagen component of bone (which resists tension) is much weaker than the mineral component (which resists compression). Indeed after a simple transverse fracture, the bone is still able to resist compression. If the fracture can be reduced and a way can be found of taking up the tension, for example a plate (Fig 2.4-31b–c), then loading the femur (eg, walking on it) will actually increase the compression at the fracture site. For this to function the medial (compression) cortex must remain intact (Fig 2.4-31d–e). It will not work if the fracture is multifragmentary.

Fig 2.4-29   If a stick is bent until it breaks the fracture starts on the tension side.
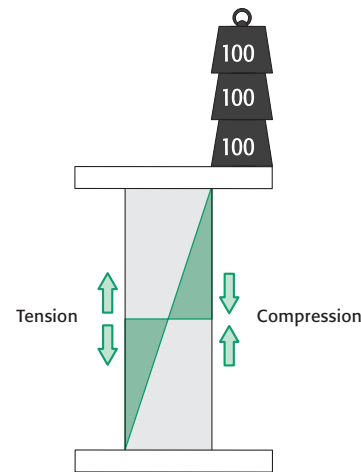
Fig 2.4-30   A beam loaded eccentrically has one side under tension and the other under compression.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

Although a lateral plate on a transverse femoral fracture is a convenient example of a tension band and an acceptable way of managing this injury, intramedullary nails are preferred as they work equally well, cause less soft-tissue damage, and can be used for almost all femoral diaphyseal fracture patterns. The tension band principle is sometimes applied in the management of subtrochanteric femoral fractures with a blade plate (Fig 2.4-32).

Tension band fixation provides absolute stability at the fracture site, but compression is also "dynamic" in that the greater the load applied the greater the compression across the fracture. This causes confusion, but these two concepts are not mutually exclusive. When someone lifts his or her left foot off the ground, the right foot does not move (absolute stability) but the load under the foot doubles (increased compression).

Fig 2.4-31a–e
a   The femur is normally loaded eccentrically because the femoral head is offset.
b   In a transverse femoral fracture failure of the bone will start on the tension side.
c   A plate applied on the tension side resists the tension forces and allows the bone to continue to resist compression forces.
d   If the medial cortex is not intact…
e   failure results.
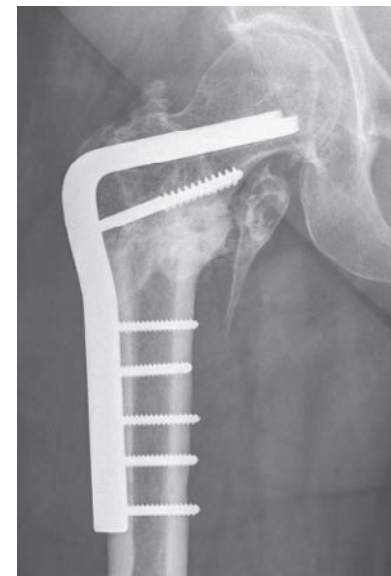
Fig 2.4-32   Blade plate applied as a tension band plate to treat a subtrochanteric fracture.

2.4.4.2 Tension band wiring

The most common application of tension band in trauma surgery is the tension band wire used for managing olecranon and patella fractures.

Biomechanically the olecranon is an inverted seesaw, with the distal humerus acting as the pivot while triceps and brachialis muscles pull on each side of the proximal ulna (Fig 2.4-33a). The dorsal surface of the olecranon is therefore under tension and the ventral surface under compression. A simple transverse fracture can be held accurately, reduced with two parallel K-wires. The tension band is supplied by a figure-of-eight looped wire over the tension surface, anchored by the K-wire ends proximally, and a hole through the ulna distally. The wire is tightened equally on both sides by twisting to apply compression. Once fixed, any pull on the triceps muscle increases the dynamic compression across the fracture site (Fig 2.4-33b).

The situation in the patella is similar. This time it is the insertion of the quadriceps and patellar tendons onto the superficial surface of the patella which provides the load and the femoral condyles which acts as the pivot, setting up tension at the superficial and compression at the deep surface of the patella. Failure occurs in tension, usually caused by a fall on the front of the knee. Provided the fracture is a simple transverse one and there is no fragmentation of the deep cortex, it can be reduced over two parallel K-wires and a superficial tension band wire applied round the ends of these wires (deep to the tendons) is tightened to provide compression. The pull of the quadriceps then increases dynamic compression across the fracture as the knee flexes and extends (Fig 2.4-34).

The tension band principle can be applied in other fractures when the anatomy provides for eccentric bone loading, and the fracture is only in two parts, other sites where this applies include the medial malleolus and the base of the fifth metatarsal.

2.4.4.3 Conclusion

Tension band fixation provides absolute stability at a fracture site, although the amount of compression between the fracture fragments may vary with the load applied and is therefore considered to be dynamic. Tension bands can only be used when the compression cortex opposite the tension band is intact. If it is not, then an alternative method of fixation must be used.

a

b
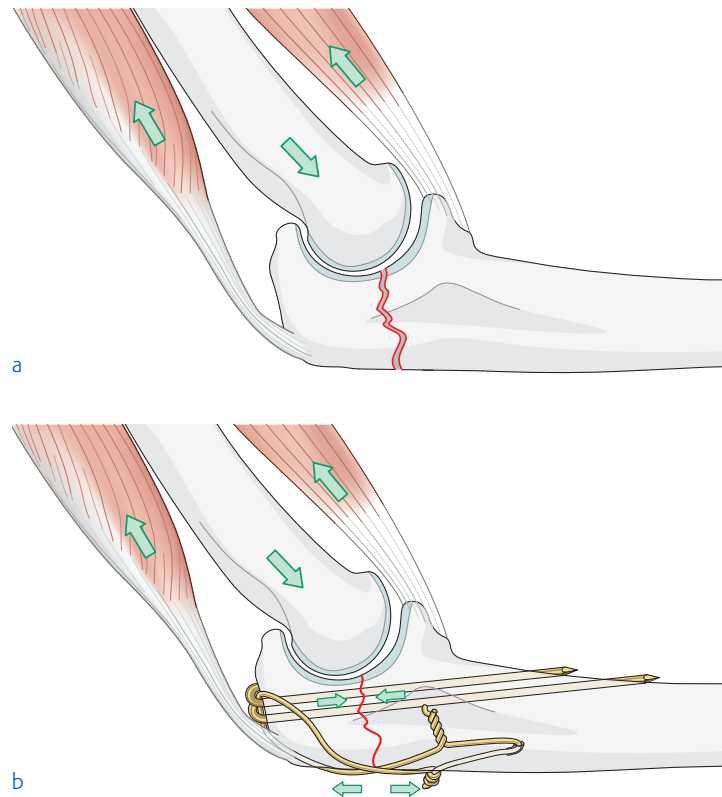
Fig 2.4-33a–b
a   The pull of the muscles across the elbow loads the olecranon eccentrically.
b   Tension band wiring applied to an olecranon fracture.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner
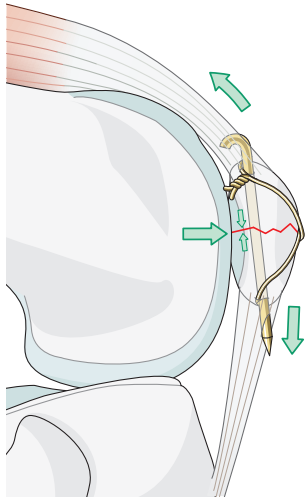
Fig 2.4-34   Tension band wiring used to fix a transverse fracture of the patella.

2.4.5   Intramedullary techniques   Merng Koon Wong

Intramedullary nail stabilization of a fracture is intended to provide relative stability at the facture site, and therefore produce conditions for fracture union by indirect healing with formation of callus. Callus implies that there is controlled movement at the fracture site under functional loading. This chapter looks at the design of intramedullary nails and some technical issues around their insertion, and considers their local and systemic physiological impact.

2.4.5.1   Nail design

The mechanical strength of an intramedullary nail depends on the design. The original Küntscher nails had a clover leaf design with an open slot which enabled the nail to grip the bone in the absence of locking bolts (Fig 2.4-35). However, the slot greatly reduced the strength and torsional stability of the nail. The introduction of locking bolts which ensure excellent mechanical linkage between nail and bone led to the development of stronger unslotted cylindrical and solid nails.
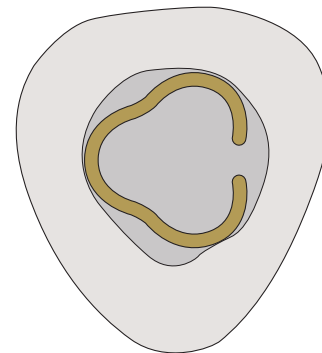
Fig 2.4-35   The clover leaf design of the original Küntscher nail.

Other factors that increase a nail's mechanical strength include the nail diameter and the thickness of the wall of a hollow nail. The material that the nail is made of is also important; steel nails are stronger but have greater rigidity than titanium ones of the same dimensions.

An intramedullary nail acts as a splint. Left unlocked it is good at resisting bending in any direction, but resistance to torsion and telescoping at the fracture site is only provided by the friction between the reduced fracture fragments and the contact between the nail and the bone above and below the fracture site. This may be enough to maintain reduction in a simple transverse fracture, but in multifragmentary fractures it is always insufficient (Fig 2.4-36). For this reason all nails should be locked by locking bolts (screws) proximally and distally to provide adequate resistance to torsional and compressive forces.

The resistance to bending deformation is a function of the working length of the intramedullary nail. The working length is defined as the distance across the fracture site between the nearest points where the nail engages the bone. In a loose-fitting nail or a multifragmentary fracture, the engagement between bone and nail is provided by the locking bolts, and the working length is the distance between those at the top and the bottom (Fig 2.4-37). With a tight-fitting nail in a simple middle-third diaphyseal fracture where the nail grips the diaphyseal bone on each side of the fracture site, the working length is much shorter. The longer the working length the more movement will occur at the fracture site when the fracture is loaded.

Working length

Fig 2.4-36a–b
a   An unlocked nail in a multifragmentary fracture will not resist compression or rotation.
b   Locking increases rotational stability and prevents shortening at the fracture side.
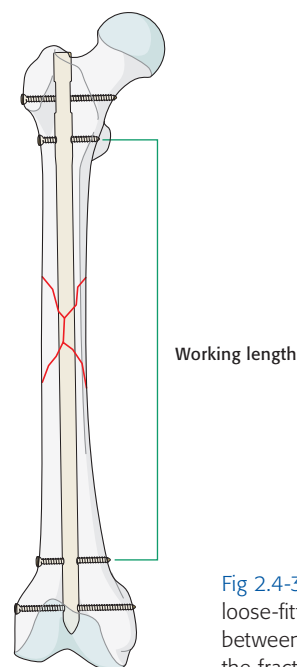
Fig 2.4-37   The working length in a loose-fitting locked nail is the distance between the locking bolts each side of the fracture.

a   b

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

2.4.5.2   Surgical technique

Reaming

Today's nails are either solid or cannulated, and both types can be inserted either reamed or unreamed. The decision to use reaming rests with the surgeon and is part of the preoperative plan.

Reaming the intramedullary canal removes irregularities and circumferential layers of bone from the endosteal surface, thus enlarging the diameter of the canal and allowing insertion of a larger nail. However, it damages the endosteal blood supply which is normally responsible for supplying the inner two-thirds of the shaft of a long bone (Fig 2.4-38). Blood supply is diverted to the
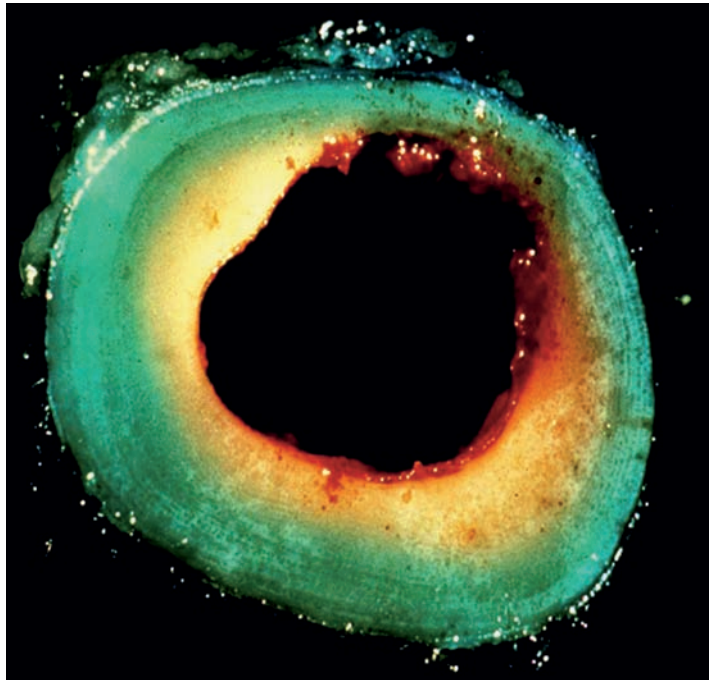
Fig 2.4-38   The effects of reaming on the endosteal blood supply of the canine tibia. The yellow area illustrates the reduction in blood flow.

periosteum to compensate for this. Reaming can also generate high pressure within the intramedullary cavity of the bone which forces debris into the venous circulation. This is believed to increase the systemic inflammatory response implicated in the pathogenesis of acute respiratory distress syndrome (ARDS) and multiple organ failure (MOF). The outcome of this is not yet fully understood. In healthy patients with single fractures the systemic effects of reaming are rarely a clinical problem. However, in severely injured patients or those with a significant lung injury, reaming should be kept to a minimum or avoided (see chapter 2.9).

Although reaming damages the endosteal blood supply to the bone, for reasons that are not fully understood, fractures treated with reamed nails heal faster than those in which unreamed nails have been used. Therefore reaming is generally recommended, unless there is a specific contraindication.

Reaming should always be performed over a guide wire placed across the fracture and is carried out in 0.5 mm increments to a diameter of 1.0 to 1.5 mm more than the nail diameter. The reamer heads should always be rotated at full speed. How much to ream is at the discretion of the surgeon, who has to balance the need for minimizing bone resection and endosteal damage against using a nail of sufficient diameter to hold the fracture until the bone has healed without the nail breaking.

Reamer heads should always be kept sharp. The use of blunt reamer heads and the prolonged reaming of hard bone can both generate considerable heat. If the temperature is permitted to rise high enough, it can cause thermal necrosis of the bone. Prolonged rotation of a reamer head which is not making progress must be avoided. Should this occur, the reamer head must be withdrawn and the flutes of the reamer cleared of bone debris while it cools down before continuing.

Fracture reduction

Most intramedullary nails are inserted through a small incision away from the fracture site. The fracture is reduced by indirect means to allow a guide wire or an unreamed nail to pass across it. This can be technically difficult, (particularly in the femur); moreover, this part of the procedure generally relies on radiological assistance. A small additional incision over the fracture site and a quick direct reduction with the help of a finger or a Schanz screw is preferable to a prolonged struggle to achieve the same result using a closed technique.

In those fractures in which accurate reduction is important, accurate open reduction under direct vision is preferable to inaccurate closed reduction. This is particularly important in subtrochanteric femoral fractures, deformity is due to the differential pull of the muscle attachments and poor reduction frequently leads to nonunion.

Nail insertion

Insertion of an intramedullary nail basically involves sliding a metal rod into a tube of bone. The femur has an anterior bow whose radius differs between patients. As the intramedullary nail has a fixed radius of curvature it generally needs to deform slightly within the femur to advance down the intramedullary canal. The tibia is almost straight, but the insertion point for a nail is anterior to the long axis of the medullary canal, which means that the straight portion of the nail needs to deform temporarily during insertion.

Since the geometry of the nail is fixed and the ability of the nail to deform in the medullary canal on insertion is limited, the entry point will determine the rest of the nail's path down the medullary canal. Therefore, finding and knowing the correct entry point is the most critical step of the procedure. If the entry point is wrong, the nail can deform the fracture site, get stuck, and even cause additional fractures (Fig 2.4-39). In addition, since the chosen entry point is then reamed to the diameter of the nail to be inserted (up
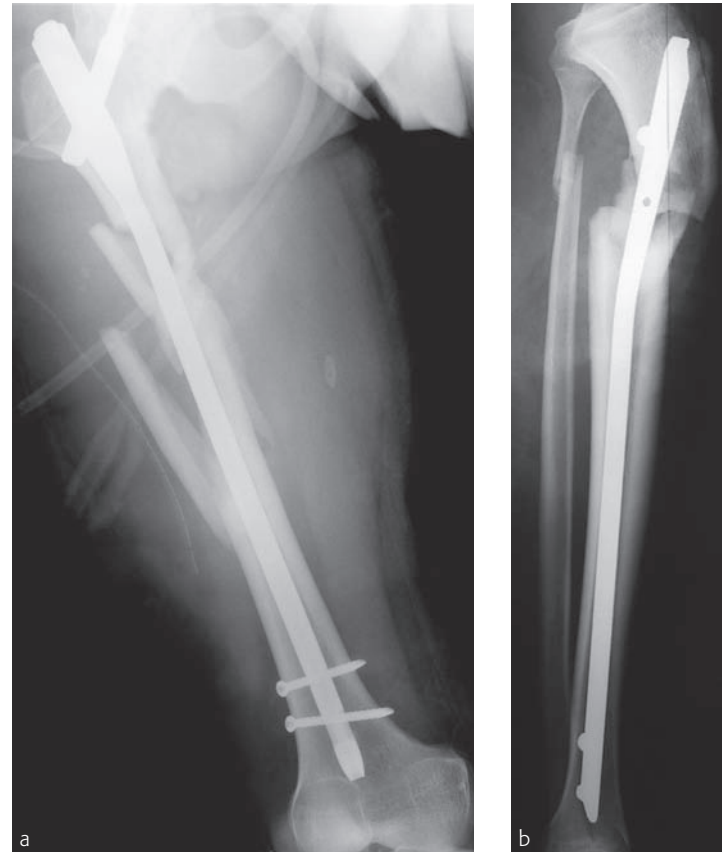
Fig 2.4-39a–b
a   Correct entry point for an intramedullary nail.
b   Incorrect nail entry point has led to malreduction at the fracture site.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

to 15 mm, depending on bone size); subsequent minor adjustment to the entry point is almost impossible as invariably any new entry point merges into the old one. Different nails require different entry points, particularly in the femur, and it is important to ensure that the surgeon is aware of this as part of the planning process.

Insertion of locking screws
Proximal interlocking screws are usually inserted with a jig attached to the top of the nail; however, this does not work with distal locking screws, unless the nail is short (as in some types of proximal and distal femoral nails). Slight nail deformation on insertion makes long jigs inaccurate most of the time. Distal interlocking screws are targeted with the help of an image intensifier and are inserted freehand or with the use of a radiolucent power tool attachment.

2.4.5.3   Elastic nails
Flexible intramedullary nails are solid titanium rods between 2.5 and 5 mm in diameter: they can be bent to a predetermined curve or even S-shape.

The ability to prebend and shape the nail means that they can be introduced from the metaphyseal/diaphyseal junction of long bones avoiding interference with the growth plate. The fracture is reduced by indirect reduction with traction, after which two prebent nails, each about one third the diameter of the intramedullary canal, are passed across the fracture site (usually one from each side), under image intensifier control. The nails are positioned symmetrically with the apex of their curve at the level of the fracture and their ends braced against the opposite cortex above and below the fracture site (Fig 2.4-40). The elasticity in each nail holds the fracture out to length, while any tendency to overcorrect the reduction is counteracted by the symmetrical forces of the two nails. Therefore nails of the same size must be used, as nails of unequal diameter would cause an imbalance of forces in each direction and would lead to a loss of reduction.

2.4.5.4   Conclusion
Intramedullary nails provide relative stability at a fracture site to maintain axial and angular alignment and rotational stability. Inserting them via the correct entry point is critical and they should always be locked proximally and distally.
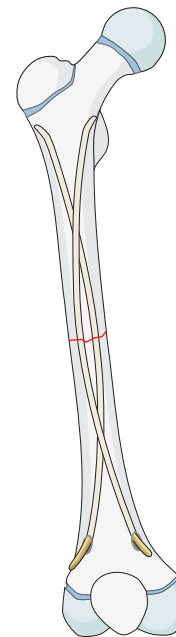
Fig 2.4-40   A pediatric femoral fracture treated with two elastic nails.

2.4.6 Extramedullary techniques Michael Baumgaertner

Throughout this text, the need to protect and preserve the vitality of the fracture zone has been stressed as a prerequisite for uncomplicated bone healing and return of limb function. It is well known that the endosteal blood supply is usually absent for any butterfly fragment and that the periosteal blood supply is damaged with surgical exposure. Therefore, the more fragments there are in a fracture the less the ability of the surgeon to anatomically reduce and absolutely stabilize each piece without devitalizing the bone. This is the setting in which spanning or bridging the fracture zone, without attempting to piece together the fragments, can be most helpful. This chapter describes the use of plates and external fixation to impart relative stability to fractures by bridging.

Relative stability by definition means that there is some motion at the fracture site. It may seem counterintuitive but it is critical to understand that the simplest (two-part) fractures have the potential for the greatest relative motion at the fracture site. Conversely, the more fragmented the fracture the smaller the relative motion (termed "strain") is at each of the many fracture surfaces. Imagine holding a 1-meter stick with your hands at each end. If the stick has a single break in the middle, any motion of either hand is transmitted to the single "fracture surface" (Fig 2.4-41a). Assume the stick is broken into several pieces that act like the links of a chain. Now the motion between the hands is distributed along each of the links, and the relative motion at any particular fracture surface (chain link) is much smaller than in the first situation (Fig 2.4-41b). Research by Stephan Perren at the AO Center has confirmed this relationship, demonstrating that bone can only form in an environment where the relative motion at the fracture site is small, regardless of the overall motion at the ends of the bone.

a

b
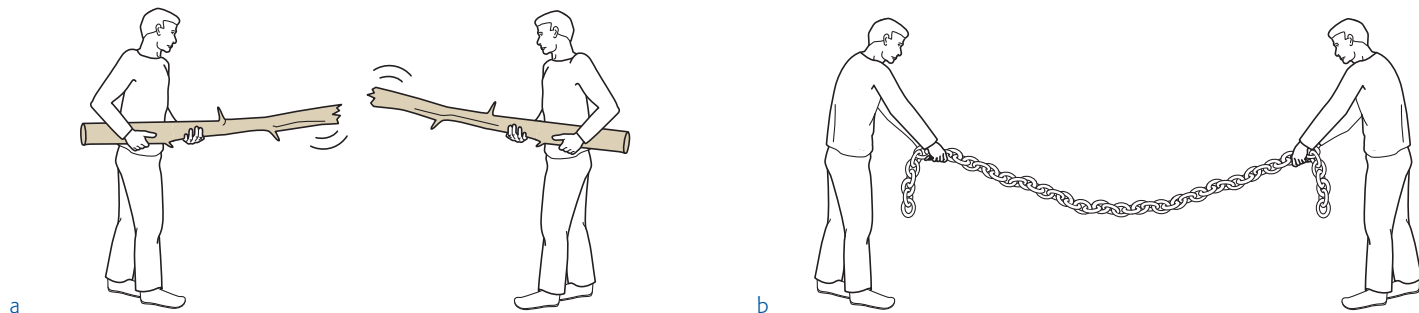
Fig 2.4-41a–b
a   With a single break in a long stick held at arms' length, small movements of the hands lead to considerable movement between the stick ends.
b   With a chain held in the same way, the movement between each link in the chain is much smaller.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

2.4.6.1   Bridge plating

Indications

The most common indication for use of a bridge plate is for a metaphyseal fracture with multiple fragments. In the upper limb, fragmented, purely diaphyseal fractures (type C) are also typically treated with bridge plating, since intramedullary nailing is less ideal in these bones. Occasionally, a bridge plate is used to treat a pediatric diaphyseal fracture. Bridge plating is rarely indicated in the treatment of a nonunion.

Reduction

Bridge plating requires indirect reduction, as the fracture fragments are not exposed or directly manipulated, and visual inspection of the fracture lines cannot be used to judge the correct position of the distal segment relative to the proximal one. The goal of indirect reduction is to position the distal fragment at the right length, the correct angles (axis), and the correct rotation to the proximal fragment without concern for the position of each of the fractured fragments between the bone ends. In other words, the distal joint is returned to its correct 3-D location relative to the proximal joint and the segments in between are allowed to remain imperfectly positioned (Fig 2.4-42).

To use indirect reduction techniques, careful preoperative assessment and planning is mandatory and additional tools are often needed at the time of surgery. High-quality, biplanar x-rays of the injured side are required. Frequently, images of the uninjured side are also required to serve as a template. The patient must be positioned on a suitable operating table so that intraoperative image intensification can be used. Skeletal traction applied with the help of a fracture table is an excellent method of indirect reduction. Additionally, instruments, such as a femoral distractor, Schanz screws, and pointed reduction clamps (applied through small stab incisions in the skin) allow control of major fragments without devitalizing the fracture zone.
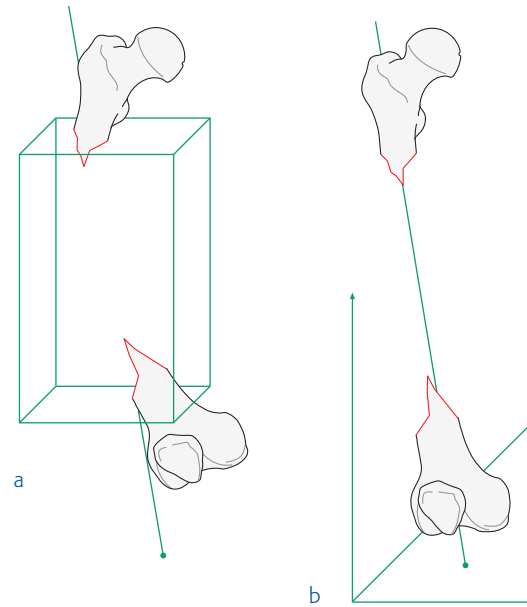
Fig 2.4-42a–b
a   Fracture of the femur with displaced proximal and distal fragments.
b   The positions of the proximal and distal femur have been restored and the axis correctly aligned. Exact reduction of any diaphyseal fragment is not necessary.

Implant options

In theory, any plate can function as a bridge plate. In practice, the LC-DCP and angled blade plates have been particularly valuable for this application, and more recently both straight and precontoured periarticular LCPs are proving useful. Because reconstruction plates and tubular plates tend to bend under relatively small loads, they have a limited role in bridging complex fractures.

Regardless of plate design, bridge plating requires significantly longer plates with a relatively low-screw "density" (the number of screws divided by the number of holes available). Typically three or four screws are used to gain adequate fixation at each end

of a plate bridging a diaphyseal fracture, spaced over a 5- to 6-hole plate segment leaving two- to three-screen holes unfilled. Additionally, at least two or three holes over the fracture zone are left empty to avoid concentrating all bending forces onto a small area of the plate. This significantly decreases the risk of early fatigue failure of the implant.

As noted earlier, the most common indication for bridge plating is the complex metaphyseal fracture (with or without articular surface involvement). Because the articular segment is often not long enough to accept three or four screws spaced over 5 to 6 holes, a fixed-angled condylar blade plate or more recently a locking condylar plate is preferred. Both devices offer secure fixation of a small articular segment that can be balanced to the fixation achieved by the long plate on the diaphyseal end of the fracture.

Locking plates

With development of the locking and "combi" holes, confidence has grown in the bridge plate technique. For diaphyseal bridging, locking plates have two clear advantages over conventional plates and at least one theoretical advantage.

Laboratory studies as well as an increasing number of clinical trials have shown that locked constructs are superior when fractures occur in osteoporotic bone, particularly when using bicortical locking screws. Conventional plates require bone/plate friction for stability, and this is largely dependent on the pullout strength of the screw. Osteoporotic bone has markedly reduced pull-out strength, leading to sequential loosening of screws, toggling, and failure of the bone implant interface. Locking plates achieve stability through the geometry and rigidity of the screw/plate interface, and as such there is no sequential, independent loosening of screws.

Most current locking plates have coordinated aiming jigs and insert drill guides which facilitate minimally invasive plate and screw application.

Conventional plates, even the limited contact plates, require some compression onto the cortex to achieve stability, and cortical compression detracts from local bone perfusion. Since locking plates do not require bone/plate compression for stability, bone blood supply is enhanced, theoretically improving fracture healing and remodeling.

Locking plates have also proven to be valuable in the management of fragmented metaphyseal fractures with a small articular fragment. Use of a conventional plate is frequently complicated by postoperative collapse and malalignment because of angular instability at the screw plate junction (Fig 2.4-43a–b). Although the fixed-angled condylar blade plate offers excellent angular stability,

a   b   c
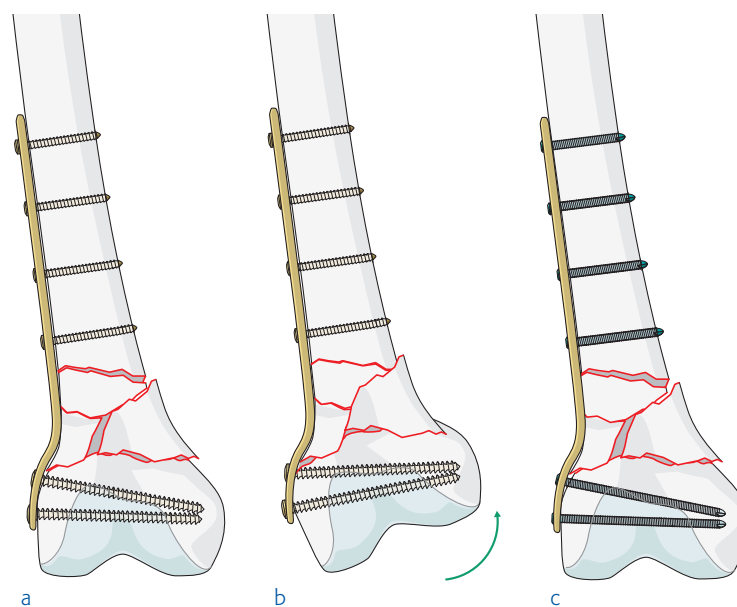
Fig 2.4-43a–c
a–b Fixation of a multifragmentary distal femoral metaphyseal fracture with conventional plate and screws provides little angular stability and is prone to collapse.
c   The LCP with locking screws provides good angular stability resulting in a decreased risk of collapse.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

it is technically more difficult to insert and almost impossible to perform with a minimally invasive technique. The LCP addresses both of these drawbacks (Fig 2.4-43c).

The only drawback of using locking plates for bridging is cost. The plate and particularly locking screws are significantly more expensive. Also, before the advent of the "combi" hole, the plate (eg, LISS) could not be used as a reduction tool but had to be applied to a fully reduced fracture.

Advantages of a locking plate functioning as bridge plate:

- Improved stability in osteoporotic bone
- Improved stability in small articular bone block
- Decreased damage to periosteal circulation
- Easier to use with MIPO technique

2.4.6.2   External fixation

Temporary indications

External fixation is an exceptionally useful fracture stabilization technique that can be applied rapidly without any interference of the facture site, and can be used as a temporary measure. Indications for the application of external fixation can be separated into factors relating to the injured limb, the systemic injuries sustained by the patient, and to the care setting itself.

External fixation is most commonly selected because of the severity of the soft-tissue injury overlying the fracture, such as in high-grade open fractures, crush injuries, and impending or established compartment syndrome. In these clinical settings, achieving relative stability (and wound debridement if indicated) with no additional soft-tissue compromise (as would necessarily occur with formal open reduction) is the primary goal. The fixator bridges the fracture and may cross the joint in those injuries close to or involving a joint—a "spanning" external fixator. This allows the external fixator pins to be placed away from the ultimate location of any subsequent internal fixation. The fixator

holds the extremity and muscles slightly distracted to minimize contractures.

External fixation is often appropriate for closed injuries when the patient's systemic condition will not tolerate more invasive and prolonged procedures necessary for definitive internal fixation. Hemodynamic instability, coagulopathy, hypothermia, closed head injury, or pulmonary compromises are common patient factors which can mandate the use of temporary external fixation as part of a damage-control strategy (see chapter 2.9). Last, the surgeon may elect to temporarily stabilize the fracture with external fixation because the necessary equipment (or expertise) for definitive ORIF is not available at the time of presentation or at the facility to which the patient presents. In all these situations, the external fixator offers enough stability to the fracture to prevent further soft-tissue compromise as well as to allow effective nursing and transport of the often multiple-injury patient.

Definitive indications

In many trauma centers, the use of external fixation for the definitive stabilization of fractures has declined with the development of bridge plating and particularly locked plating. Nonetheless, it is an effective means of imparting relative stability to the fracture zone. Fragmented metaphyseal/diaphyseal fractures, particularly when there is associated soft-tissue compromise, can be effectively stabilized with external fixation. Typically, single-plane external fixation is used but biplanar ("delta frame") and ring fixation can also be used. Special situations including deformity correction and infected fractures are frequently managed with definitive external fixation. Although the initial frame may span the joint, definitive external fixation is generally confined to a single-bone segment (eg, femoral or tibial shaft fractures) allowing early movement at the adjacent joints.

It is important to consider the indication for external fixation in order to design the best construct for that particular clinical problem. An ideal fixator for the temporary spanning of a complex,

open fracture near the knee has the pins far away from the zone of injury and out of the site of the planned internal fixation. The frame is uniplanar, with the bar well away from the skin to facilitate wound care and accommodate swelling. Radiopaque clamps should be used so as not to compromise preoperative planning. This frame design should be different than a frame applied to definitively treat a fracture when adequate construct stiffness and patient tolerance are more important considerations.

Application technique

There are two basic application strategies when stabilizing a fracture with external fixation. In the simplest situation, one can apply the external fixator to a reduced fracture. This requires a minimum of four pins and a single bar. The most proximal and distal pins are inserted into the bone. Four universal clamps are threaded onto a single bar and the upper and lower clamps are connected to the pins. The length, angulation, translation, and rotation are corrected and the clamps tightened to achieve reduction. Finally, the two pins nearest the fracture are inserted through the two empty clamps to provide additional stability. Note that the position of the pins nearest the fracture site is determined at least in part by the position of the clamps.

Alternatively, a modular reduction technique can be used when two Schanz screws are applied to each major fragment, effectively making a "handle" with a rod for each segment. In this technique all the external fixator pins can be inserted before the fracture is reduced. The fracture is reduced by maneuvering a third rod connected with tube-to-tube clamps to the "handles" to finally maintain the reduction. A minimum of four Schanz screws, four universal clamps, three rods, and two rod-to-rod clamps are needed for this technique (Fig 2.4-44).

Advantages of the single-bar technique include reduced cost of components, easier care and cleaning, and a potentially stiffer construct which allows axial dynamization. Disadvantages are that the positions of the two pins closest to the fracture are deter-

mined by the position of the clamps on the bar. This may result in suboptimal positioning of the pins in relation to the soft-tissue injury.

The modular technique offers the advantage of being technically easier to apply and to modify because the position of each individual pin is determined by soft-tissue injury and not by the design of the implant. It offers wide applicability for numerous fracture

a   b   c
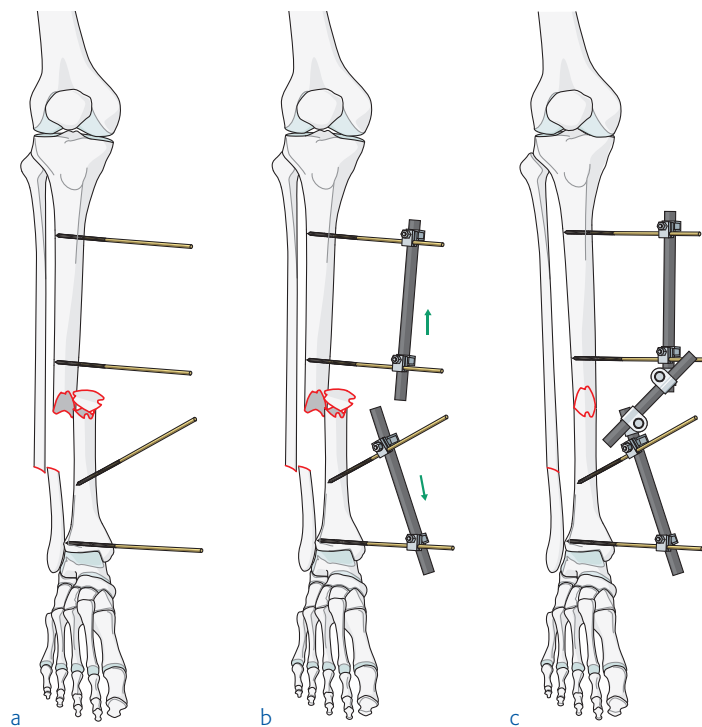
Fig 2.4-44a–c   Type B diaphyseal tibial fracture.
a   Two pins are inserted in each main fragment outside the zone of injury.
b   Fixed to a bar by universal clamps, two handles are produced for indirect reduction.
c   The two bars (handles) are united by a third bar and two rod-to-rod clamps and indirect reduction is performed.

Authors   Piet de Boer, Daniel Saris, David J Hak, Matthew Porteous, Merng Koon Wong, Michael Baumgaertner

locations and patterns. It allows for repeated debridement and re-reduction in the setting of open fractures, and modular components can be used to temporarily span joints.

2.4.6.3   Conclusion

The use of temporary spanning external fixation in preparation for definitive treatment is a useful method of minimizing some of the risks associated with open reduction and internal fixation, particularly that of infection. Although displaced articular fractures require direct manipulation and visual confirmation of anatomical reduction, metaphyseal and diaphyseal complex fractures are often best managed by indirect reduction and bridge plating (Fig 2.4-45). This technique minimizes damage to the remaining blood supply to the fracture zone. Axial realignment and relative stability provide an acceptable strain level for bone healing, while at the same time minimizing the risk of implant fatigue by distributing these forces over a longer segment of the plate.
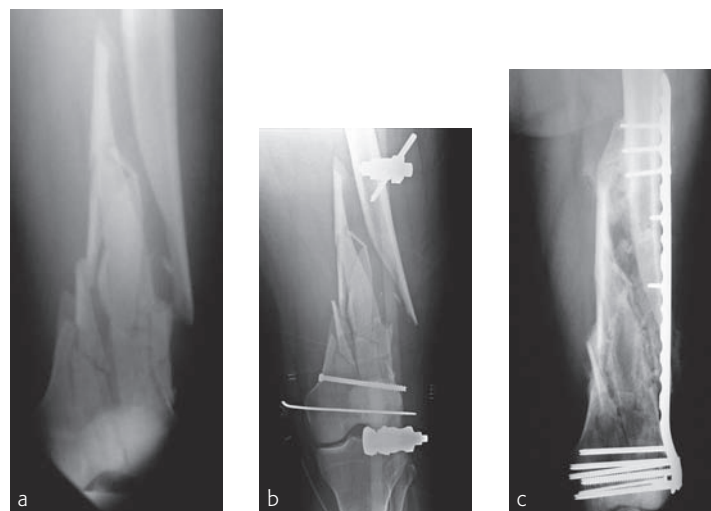
Fig 2.4-45a–c
a   Multiple-trauma patient with distal femoral fracture (33-C2).
b   A patient underwent percutaneous fixation of joint spanning fixator.
c   Following formal ORIF of joint surface and indirect reduction and bridge plating with locked condylar plate. Note: axial reduction and solid healing by callus formation.

Factors	(Effect) Advantages	Disadvantages
Increase pin-pin spread within each fragment	+++ Frame stiffness	Possible pin irritation near joint, encroachment on zone of injury
Decrease bar-to-bone distance	+++ Frame stiffness	Does not accommodate swelling; soft-tissue impingement; may interfere with wound management
Increase pin and/or bar diameter	++ Frame stiffness	Pin-site problems, fracture
Increase pins/fragment	+ Frame stiffness	+Cost, pin-site problems
Add second bar ("stacked")	++ Frame stiffness	++Cost, bulk of frame
Add second frame ("delta") in different plane	+++ Frame stiffness	Compromise wound access, pin-site issues, bulk, cost

Tab 2.4-2   Factors influencing external fixator stiffness and stability.

2.4.7 Further reading

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2.5   Diaphyseal fractures

2.5   Diaphyseal fractures

2.5.1   Introduction

The diaphysis is the shaft section of a long bone. Its function is the transmission of load between the two ends (epiphysis and metaphysis) of the bone (Fig 2.5-1). Diaphyseal bone is cortical and designed not only to transmit load between the joints but also to be strongly resistant to bending. Bones have both an internal (endosteal) blood supply through a nutrient artery and an external blood supply from the overlying periosteum.

In this chapter the principles of management of diaphyseal fractures are examined and the characteristics of the different long bones are briefly presented.

Most of the principles apply equally to children and adults. Although with children's quicker healing and much greater potential for remodeling and correction of any deformity, their fractures are much less likely to require surgical intervention.

All fractures have to be evaluated in the context of the patient as a whole, taking into account local factors including the state of the soft tissues, the quality of the bone, whether fractures are isolated, or the patient has had multiple injuries. General patient factors, such as age, health, occupation, daily activities, and treatment expectations also need to be considered.

Mechanical considerations

Inaccurately reduced diaphyseal fractures result in malunion. The bone can heal in a shortened, angled, or malrotated postition, or any combination of the three. The effect of a malunion depends on its severity and the bone affected.

The function of the legs is to move the body (locomotion), efficiently transmitting body weight to the ground. To optimize this, the leg has a mechanical axis defined as a line between the center
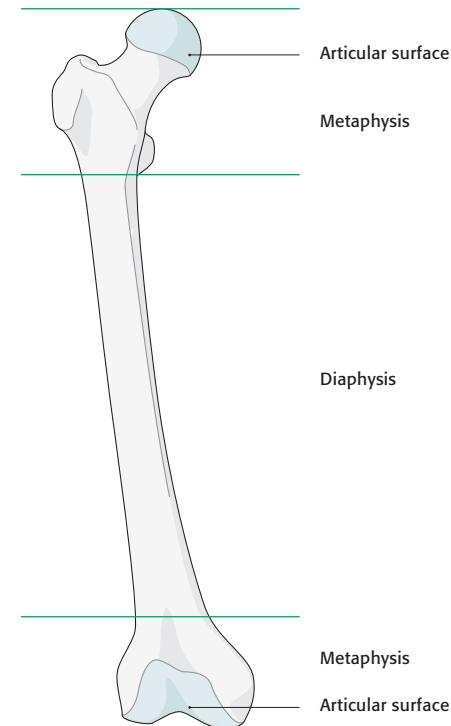
Fig 2.5-1   Femur illustrating the diaphysis and adjacent parts of a long bone.

Articular surface

Metaphysis

Diaphysis

Metaphysis

Articular surface

of the femoral head and the center of the ankle joint. This line should pass through the center of the knee joint (Fig 2.5-2). Any lower limb diaphyseal fracture that heals with persistent angulation will alter the mechanical axis which will change the way weight is distributed across the knee and ankle. In practical terms, angulation of more than 10º in the coronal plane or 5º in the sagittal plane is likely to increase the risk of developing secondary osteoarthritis. In younger patients even smaller degrees of deformity may cause trouble. However, most patients will tolerate up to 1 cm of shortening and 10º of malrotation in the leg.
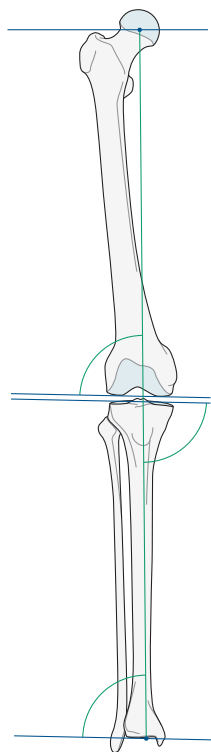
Fig 2.5-2   The mechanical axis of the leg is a line drawn between the centers of the hip and the ankle joint. This axis should normally pass through the center of the knee joint when the limb is weight bearing.

A much greater degree of residual deformity can be tolerated in the humerus, as it does not bear weight and angular deformities can be compensated by the mobility of the shoulder. Up to 30º of angulation, 20º of malrotation, and 3 cm of shortening is usually considered acceptable.

In contrast, any deformity after a diaphyseal fracture of the forearm will lead to a loss of forearm rotation. Perfect function (pronation and supination) requires the radius to rotate around the ulna, and this is prevented by any loss of shape in either bone. For this reason, the whole forearm is regarded as a joint. Therefore all adult forearm fractures require anatomical reduction wherever possible.

Aims of treatment

The treatment aim in diaphyseal fractures (with the exception of the forearm) is to restore the joint surfaces at each end of the bone to their correct orientation relative to each other. In practical terms this means aiming to restore the length, rotation, and overall alignment of the bone. It is however not usually necessary or desirable to achieve perfect reduction of every fracture fragment, as attempting to do so may cause damage to the blood supply to the fracture (particularly when it is multifragmentary), and result in delayed healing.

Initial assessment

Assessment of a patient with a diaphyseal injury should always start with resuscitation of the patient using advanced trauma life support (ATLS) or a similar protocol (see chapter 2.9). Long-bone fractures are often obvious and sometimes dramatic. It is important not to focus on them to the exclusion of a less obvious but more serious or life-threatening injury.

Once other injuries have been excluded, a history of the mechanism of the injury will often give a hint to the specific fracture pattern. An examination needs to assess the neurovascular status of the limb, the state of the overlying soft tissues, whether the

Author   Klaus Dresing

fracture is open or closed, and if there is any possibility of a compartment syndrome (see chapter 2.3). Adequate x-ray imaging is mandatory, with a minimum of two views, at 90º to each other, showing the joint above and below the fracture (see chapter 2.7).

2.5.2   Management

Nonoperative treatment

In the upper limb most humeral diaphyseal fractures can be managed nonoperatively with a splint or cast. Single-bone undisplaced fractures of the forearm may also be treated with a cast.

In the lower limb, femoral diaphyseal fractures in adults can be treated with skeletal traction, although this requires prolonged bed rest. For functional and economic reasons surgery is usually the treatment of choice in most Western countries.

Minimally or undisplaced tibial diaphyseal fractures can be managed successfully in a plaster cast or other type of splint. It is often possible to reduce more displaced fractures by manipulation with the patient under anesthesia and then hold the reduction in a cast, which should include both the knee and the ankle joint. If there is any risk of soft-tissue swelling the initial cast is split (once it has hardened) and the leg elevated. The cast can be completed once any swelling has diminished. Regular x-rays are required to ensure that the reduction is maintained.

Nonoperative treatment of fractures is not an easy option. It requires experience and close supervision to achieve acceptable functional results.

Indications for surgery

The decision to fix a diaphyseal long-bone fracture depends on the resources available and the experience of the surgical team. When these are limited, it is possible to manage most of these fractures nonoperatively, although this may result in a degree of malunion and some loss of function. However, there are some absolute indications for surgery. These include stabilizing the long-bone fractures, particularly the femoral shaft, of multiple-injured patients that is potentially lifesaving. The timing and method of stabilization depend on the general condition of the patient (see chapter 2.9). Limb-saving indications for fixation include open fractures, vascular injuries requiring repair, and compartment syndrome.

Relative indications for surgery include pathological fractures through abnormal bone (eg, tumor) which will not heal unless fixed, and a fracture of the bone each side of a joint, leaving the joint "floating" (eg, a humeral and forearm fracture causing a floating elbow).

Any fracture which is unstable and difficult to keep reduced by conservative methods, or in which function would be compromised by poor reduction, should also be considered for fixation.

Operative fracture stabilization allows for rapid postoperative mobilization. This reduces the morbidity associated with prolonged immobilization, and may reduce the economic impact of the injury on both the patient and the healthcare system. However, this is achieved at the expense of exposing the patient to a risk of infection at the time of surgery. When resources are limited, it is certainly better to accept some loss of function from conservative treatment than to end up with an infected nonunion from surgery.

2.5.3   Principles of operative treatment

Timing

Soft tissues are the key to good fracture care and they, not the fracture itself, dictate the timing of any surgery. Open fractures and those with associated neurovascular injury or compartment syndrome require immediate intervention (see chapter 2.3).

In most injuries timing is not critical; but, in general, early intervention is advocated to minimize the period a patient spends immobilized. However, when there is significant swelling or soft-tissue damage, surgery should be delayed with the limb splinted or stabilized to allow any swelling to settle. A temporary external fixator or traction and elevation of the limb may be used. Operating through damaged soft tissues is likely to lead to skin necrosis, infection, and delayed or nonunion of the fracture.

The details of any surgery, including the method of reduction, implant to be used, and rehabilitation information should be planned ahead and not decided during the procedure. This is particularly important when sequential-staged procedures are required which may involve more than one specialty (eg, plastic surgery to cover a skin defect in an open fracture). Planning is described in detail in chapter 2.8.

Reduction

In diaphyseal fractures the restoration of axis, length, and rotation of the bone are essential for a good outcome, although the reduction of individual fragments may not be so important. Closed reduction using indirect techniques is less likely to disrupt the blood supply to the bone fragments and is therefore the first choice whenever possible. During reduction, it is important to maintain an understanding of the effect that any manipulation might have on the soft tissues. A small incision and insertion of a finger or instrument to facilitate a difficult reduction will cause much less damage than prolonged attempts for closed reduction. Further information on fracture reduction and the techniques that can be applied are provided in chapters 2.10 and 2.11.

Choice of implant

Diaphyseal fractures can be managed with plates, nails, or external fixators. External fixators are generally reserved for cases in which internal fixation is contraindicated either because the patient is too severely injured or unwell to undergo internal fixation (see chapter 2.9) or because the nature of the local injury (eg, severe soft-tissue loss or contamination associated with an open fracture, or an infected nonunion) makes internal fixation unsafe.

For fractures of the diaphysis of the femur and tibia, closed locked intramedullary nailing is normally considered the treatment of choice. The nail provides angular stability, while the locking bolts usually provide sufficient axial and rotational stability to allow early weight bearing and a fast return to full function (see chapter 2.4.5).

Plating is an option for all diaphyseal fractures. Before applying a plate it is important to decide on it's exact mode of function. In the forearm when anatomical reduction and absolute stability is required, it can be used as a protection plate once the fracture has been reduced and held with a lag screw. For transverse fractures compression plates can be used. While these options are also available in the lower limb they are less commonly applied because of the widespread use of nails. Plates remain a reasonable option for simple diaphyseal fractures, or when the fracture line extends into the metaphysis making the use of a nail technically difficult or impossible. Clinical trials suggest most humeral diaphyseal fractures have a better outcome when fixed with a plate than a nail.

In more complex multifragmentary injuries of any diaphyseal or metaphyseal fracture, the need to preserve the blood supply to the bone and to avoid additional soft-tissue damage usually dictates that if a plate is to be used it should be applied as a bridging plate, providing relative stability. Bridging plates should not be used in simple (two-part) diaphyseal fractures, as there is a high incidence of delayed union or nonunion.

Postoperative care

Since the restoration of function is the surgeon's primary aim, adequate postoperative care is as important as good surgery. Definitive fixation must allow for immediate or early mobilization of adjacent joints. Physiotherapy should be directed at this goal and continued until normal limb function has been achieved.

Author   Klaus Dresing

Weight-bearing status is at the discretion of the surgeon and depends on their perception of the strength and stability of the fracture fixation, and when there are multiple injuries, the ability of the patient to control their weight bearing by using crutches.

The outcome of a diaphyseal fracture depends on the severity of the original injury, the correct application of an appropriate method of management (conservative or surgical), and good rehabilitation. Fractures caused by low-energy trauma that have been well managed can be expected to make a full functional recovery. More severe injuries with serious bone and soft-tissue damage are unlikely to heal as well, although carefully planned management and rehabilitation ensure the best outcome.

2.5.4   Further reading

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2.6   Articular fractures

2.6.1   Introduction

More than 100 years ago one of the pioneers of operative fracture treatment—Albin Lambotte from Belgium—stated that fractures involving a joint should be reduced anatomically and fixed rigidly with screws and plates to allow early motion of the affected joint, as only then could an acceptable return of function be expected. Furthermore, Lambotte also stressed the importance of soft-tissue care and supported his recommendations with many impressive clinical examples and a regular follow-up of his patients.

Unfortunately at that time implant and instrument design was inconsistent, materials were often inadequate, and the high risks of infection prevented most surgeons from following Lambotte's advice. It was not for another 60 years that Sir John Charnley from England and F. Pawels from Germany again strongly recommended the operative fixation of articular fractures.

Today, throughout the world a displaced articular fracture is considered an absolute indication for anatomical reduction and stable internal fixation, provided the external circumstances are appropriate for a surgical intervention.

2.6.2   Anatomy and basic principles

Joints are an essential part of the human skeleton, allowing the limbs to move. They vary in structure and form but share common features. A synovial joint has two bony ends covered by hyaline cartilage that are bound together by a fibrous capsule. The smooth, elastic hyaline cartilage serves to distribute the forces to the underlying subchondral bone. It is lubricated and nourished by synovial fluid produced by the synovial lining of the joint capsule. Synovial joints have very low friction and are more slippery than a skate on wet ice. Motion and functional loading are necessary

for the diffusion of this fluid into the avascular cartilage. Joint stability relies on the passive stabilizers of joint morphology (eg, the ball and socket shape of the hip joint) and strong ligaments as well as active stabilizers in the form of muscles that cross the joint. Disruption of any component of an articulation can result in altered joint function and mechanical loading, which in turn can trigger pathophysiological processes, such as arthrofibrosis or osteoarthritis.

Consider, for example, a displaced malleolar fracture with gaps and steps in the joint surfaces together with subluxation of the joint and malalignment of the whole leg. In Figure 2.6-1 the patient is unable to move the ankle joint, and standing on the leg is painful. With inadequate fracture reduction and particularly prolonged immobilization in a cast, the inflammatory response becomes

a   b
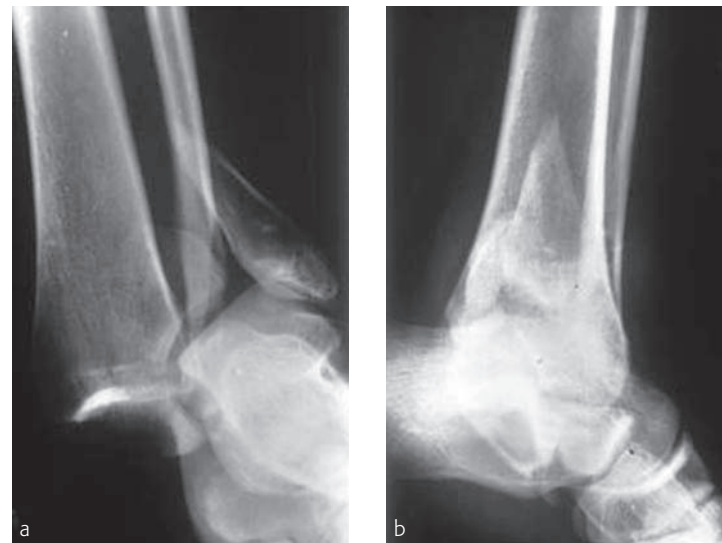
Fig 2.6-1a–b   A fracture dislocation of the ankle with considerable malleolar displacement (44-B).

accentuated, leading to fibrosis of the intraarticular hematoma which will result in joint stiffness, deformity, and functional disability.

If, however, the intraarticular effusion is removed, and the anatomical relationships are restored and fixed by interfragmentary compression that allows for immediate postoperative pain-free joint motion, the probability of a return to full function is significantly higher (Fig 2.6-2).
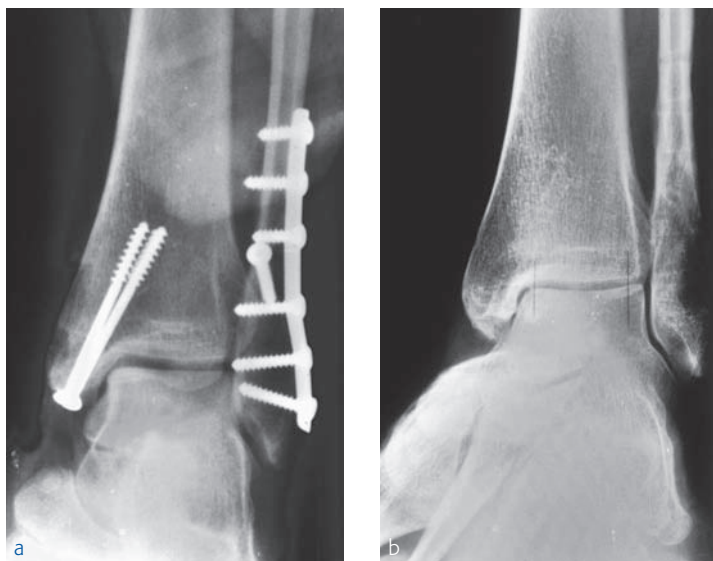
Fig 2.6-2a–b
a   Anatomical reduction and stable internal fixation restoring articular alignment.
b   Same patient, 2-year follow-up, and after implant removal with good function and no signs of posttraumatic osteoarthritis.

There is ample experimental and clinical evidence showing that articular cartilage can remain viable after blunt trauma and that it has a limited capacity for repair, mostly with fibrocartilage. It has been demonstrated in animal experiments that anatomical reduction and stable fixation with interfragmentary compression followed by continuous passive motion leads to true hyaline cartilage healing. However, any increase in stress on the articular cartilage secondary to axial malalignment (a step or gap) of the articular surface, or abnormal movements due to joint instability or meniscal tears may lead to cartilage degeneration and osteoarthritis.

2.6.3   Evaluation of patient and injury

Before starting any treatment, a careful evaluation of the patient, his or her medical history, and the mechanism of the injury is required. High-energy trauma is often associated with other injuries (polytrauma), in which case management of each injury has to be prioritized (see chapter 2.9).

Individual articular fractures may be caused by an indirect force (eg, a malleolar fracture caused by ankle inversion when slipping off a curb) or by a direct blow or impact (eg, a calcaneus compression fracture after a fall from high). The amount of energy that caused the injury is directly related to the degree of soft-tissue damage asssociated with the fracture. The soft-tissue injury will influence the timing of surgery and the type of fixation—temporary joint-bridging external fixation or definitive open reduction and internal fixation, as the soft-tissue envelope around a joint is especially delicate and vulnerable.

Any permanent joint dislocation must be reduced immediately to prevent further damage to the soft tissues. A transient dislocation may cause severe neurovascular injuries that must be excluded by a careful examination of the distal pulses and sensory-motor function.

Author   Thomas P Rüedi

Open wounds, skin lacerations, and degloving injuries are easily identified in the zone of injury and usually get the necessary attention. Easier to miss are small skin lesions or abrasions near a joint that may indicate an open connection to the joint, especially if they are leaking blood-stained synovial fluid. Other serious soft-tissue injuries, such as closed degloving, ligament ruptures, or a compartment syndrome, may also occur without there being any obvious external lesions.

The assessment of the bone injury is best done by standard x-rays in two planes (AP and lateral) that are well centered on the joint space. In most cases these are sufficient for initial decision making and planning of surgery. More detailed information can be obtained from oblique views. In complex fracture patterns or special locations (calcaneus, acetabulum, and so on), axial computed tomography with 2-D or 3-D reconstructions or magnetic resonance imaging (MRI) scans will help identify important intraarticular details. It is vital to have a comprehensive understanding of the nature of the fracture before surgery so that a detailed preoperative plan and surgical tactic can be prepared.

The Müller AO/OTA Classification enables classification of the different fractures of long bones by using standard terms which help improve communication, develop treatment protocols, and compare the outcomes. Similar attempts have been made to classify soft-tissue injuries. These are, however, much less objective and comparable than the clear x-rays of a fracture.

2.6.4   Preoperative planning

Preoperative planning is an important prerequisite to open reduction and internal fixation, especially for more complex articular fractures. Based on x-rays and soft-tissue conditions, the surgeon will have to decide how to proceed and must draw up a detailed plan that includes choice of the operating table, patient position, placement of a tourniquet, approach, site of bone graft harvesting,

special instruments for the reduction as well as implants and need for intraoperative imaging—all of which allow surgery to proceed more effectively and greatly reduces the risk of unforeseen problems (see chapter 2.8). The plan and tactic must be given to the operating room team ahead of time, allowing them to prepare everything and ask questions. Furthermore, the plan serves as an educational tool and may be used for quality control.

2.6.5   Timing of surgery

The best time for surgery is influenced by several factors, most of which are patient related; others, however, may depend on organizational and personal conditions.

"Life before limb" as a rule indicates that the general condition of the patient has priority even over a badly shattered limb. In a multiple-injured patient, it may be life-saving to amputate a severely damaged leg rather than trying to reconstruct the vessels and bone in a lengthy procedure.

Simple articular fractures, eg, a malleolar fracture, can usually be fixed immediately as most of the swelling comes from an intraarticular hematoma. In more complex fractures around the elbow, knee, or distal tibia and calcaneus, a delay of surgery is generally recommended to protect the fracture and soft tissues from further damage. Skeletal traction, or better still, a joint-bridging external fixator is the best means of temporary immobilization of the limb (Fig 2.6-3). This in turn allows the soft-tissue swelling to settle and provides time for further assessment, imaging, and detailed planning.

Vascular injuries or an imminent compartment syndrome are emergencies that require prompt action to save the limb, especially in the nonpolytraumatized patient. Any vascular reconstruction or compartment release always requires associated surgical stabilization of the bone, and the quickest and least invasive

Fig 2.6-3 Temporary joint-spanning external fixator in a badly contused proximal tibial fracture to help recovery of the soft tissues before definitive internal fixation.

method is usually by external fixator. In some fracture types the timing of surgery may be dictated by the critical blood supply to the bone, eg, a displaced femoral neck fracture in a young patient, or displaced fractures of the humeral head or the talar neck. Immediate reduction and stable fixation is recommended for all these fractures to reduce the risk of avascular necrosis.

Finally, timing of surgery may be influenced by organizational factors, such as access to the operating room, the need for assessment of the fracture by CT or MRI scan, availability of instruments, implants and image intensification, and last but not least the surgical team.

To get the best results for the patient, complex articular fractures (acetabulum, large joints, and so on) should be fixed by the most experienced and skilled surgeon in the team and only after preparation of a detailed plan. When a fracture is particularly complex and the relevant expertise is not available locally, the best interest of the patient is met by transfer to a center familiar with the management of such fractures.

2.6.6 Surgical approach

Despite today's tendencies for minimally invasive surgery and short incisions, the anatomical reconstruction of a shattered joint requires an adequate open, direct, and clear view of the articular surfaces. The open reduction and rigid fixation of the articular components may be combined with a long plate, bridging the fractured metaphysis that may be inserted subcutaneously using a minimally invasive technique (Fig 2.6-4). Only exceptionally, and mostly in simple fracture types, should the surgeon rely on arthroscopic control for joint reconstruction.

2.6.7 Articular reconstruction and fixation

This chapter's goal is not to describe the details of a surgical procedure. However, the anatomical reduction and stable fixation of the articular fragments is the most important part of surgery of intraarticular fractures. Articular reconstruction demands meticulous planning and frequently involves specialized techniques with the use of a wide range of instruments and implants. Articular cartilage is very unforgiving to surgical error and this surgery is therefore highly demanding on the whole surgical team. Larger bone defects may require a bone graft or bone substitute.

Intraoperative imaging to check the reduction using image intensification is mandatory but may be a hazard to the sterility of the procedure, if not well planned and carefully performed.

Once bony reconstruction and fixation has been accomplished, it may be necessary to reattach or suture some ligaments or a torn meniscus before the closure of the soft tissue and skin.

Author   Thomas P Rüedi

Fig 2.6-4a–d

a–b AP and lateral x-rays of complex tibial plateau fracture extending into the tibial shaft.

c   Open reduction and internal fixation to achieve anatomical reconstruction of the articular surface.

d   Incisions needed for percutaneous insertion of a long tibial LISS plate to bridge the metaphyseal and diaphyseal fractures.

e–f Postoperative x-ray of completed fixation.

2.6.8   Postoperative care

A removable splint may be justified to maintain an optimal position of the limb and joint until active muscle control has been regained as well as for a safe soft-tissue recovery. Postoperative active-assisted exercises with a physiotherapist should be started immediately. All further aftercare and the beginning of partial weight bearing depend on the quality of fixation, the compliance of the patient, and on the follow-up x-rays.

2.6.9   Conclusion

To obtain a good functional outcome, displaced articular fractures are best treated by open anatomical reduction of the joint, correct alignment of the limb, and stable internal fixation. This regimen requires considerable experience and skill.

2.6.10   Further reading

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2.7 Diagnostic methods

Author   Roshdy Guirguis

2.7   Diagnostic methods

2.7.1   Introduction

X-rays (or radiographs) are the oldest and most frequently used form of imaging in medicine. X-rays were discovered over a century ago by Wilhelm Roentgen and are sometimes called roentgenogram. X-rays produce diagnostic images of the human body on photographic film or, frequently these days, digitally on a computer screen. Diagnosis of a suspected bone fracture with x-ray is now common in the emergency department of hospitals, where the clinician's management of the patient is often guided by x-ray appearance.

Most bone fractures are diagnosed and dealt with using only plain x-ray images. Some injuries, however, may require further, more advanced forms of imaging to either show the anatomy in more detail or diagnose an occult injury which may not be apparent on initial x-rays.

2.7.2   X-rays

Taking an x-ray (radiograph) involves exposing a part of the body to a small dose of invisible, electromagnetic radiation to produce an image of the internal organs and it is especially good for imaging bone. Conventional x-rays use film similar to photographic film that must be developed but modern imaging is shifting toward computerized and digital radiography, resulting in a digital image which can be processed faster and made available for viewing on a computer screen. Digital images can be stored or transmitted electronically. This technique is now fairly widespread; consequently, many hospitals and x-ray departments have become "filmless."

Advantages of x-rays

X-rays are widely available, inexpensive (compared with other imaging modalities), fast, and easy to perform. They are particularly useful in emergency diagnosis and treatment. In fractures and dislocations, the images obtained are rather easy to interpret and are often sufficient to plan patient treatment without the need of additional investigations.

Disadvantages and limitations of x-rays

X-ray images give clear and detailed views of bone fractures, but provide little information about the adjacent soft tissues. All x-rays emit a radiation dose to the body. Although this dose can be small, the cumulative effect of numerous x-rays in a patient can eventually be harmful. Radiation exposure must therefore be kept to the minimum necessary, especially in children and women of childbearing age.

All health care professionals who use x-ray are also potentially exposed to ionizing radiation. Staff in the operating room are at particular risk because of the high number of fracture cases in which image intensification is used during surgery. Not infrequently staff operating these machines are not as highly trained as radiographers working in x-ray departments. All staff working in the operating room must be aware of these risks and take appropriate precautions to reduce the dose of ionizing radiation to which they are exposed. This risk mandates the wearing of appropriate x-ray dose-measuring devices by everyone working in the operating room.

Standard images

Many fractures and some dislocations are not detectable on a single view. Hence, it is standard practice to obtain a minimum of two views of any suspect bone or joint, usually at right angles to each other: "One view only is one view too few." Radiography of a fracture requires that there is either some separation or impaction of the fragments (Fig 2.7-1). This prerequisite is not always met, so it is inevitable that some fractures do not show up on either view. Occasionally, at sites where fractures are known to be exceptionally difficult to detect (eg, the scaphoid), it is routine to obtain more than two views.

With any long-bone fracture, it is imperative to image the whole bone which has been fractured to include the joints above and below the fracture. For example, if the fracture involves the shaft of the femur, then the knee and hip joint should also be x-rayed
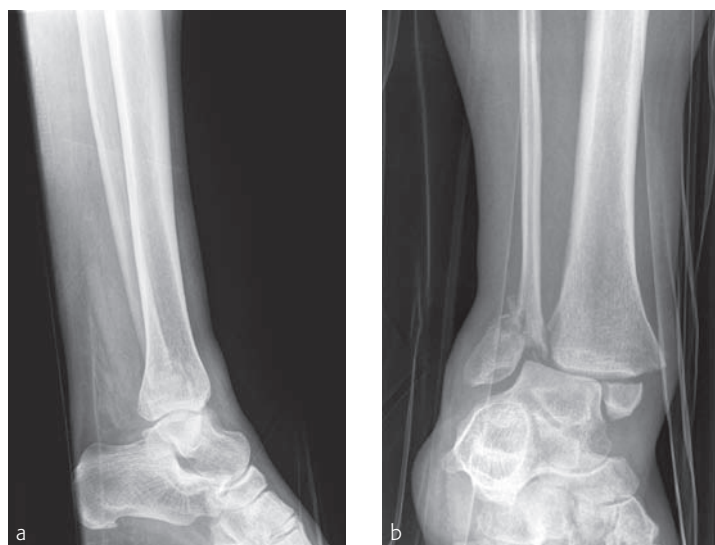
Fig 2.7-1a–b   A comminuted fracture of the distal fibula, with a fracture through the medial and lateral malleoli barely seen on the lateral x-ray (a), but is convincingly demonstrated on the AP x-ray (b).

to exclude a fracture or dislocation elsewhere. This applies especially in children who sometimes find it difficult to localize exactly where an injury has occurred. Fractures commonly missed, if inadequate x-rays are taken, include distal tibial fractures around the ankle joint where there may be a concurrent proximal fibula fracture, and a fracture of the radius with dislocation of the distal ulna (Galeazzi fracture).

2.7.3   CT scans

Computed tomography (CT) has been around since 1971, but only since the early 1990s when helical (spiral) followed by multislice CT was introduced has this imaging modality been important in the assessment of multiple-injured patients.

CT uses highly focused x-ray beams to create a set of thin cross-sectional (axial) images of bone and can also be used to image soft tissues of the chest, abdomen, pelvis, and brain. These images are accurate to within millimeters in resolution and can then be displayed in 3-D on a computer screen. They can then be carefully analyzed from any direction to look for fractures that may have been missed on the initial x-ray. If available, CT is now mandatory in complex articular fractures to enable accurate planning of joint surface reconstruction   before surgery, and may be helpful in other complex fractures (Fig 2.7-2). It can also be used to look for complications in fracture healing.

Advantages and uses of CT scans

Spiral CT has become the study of choice in the evaluation of patients with trauma in many parts of the developed world where such facilities exist. It permits rapid and relatively noninvasive imaging of the full spectrum of traumatic injuries. A patient with severe trauma can be studied with only minimal positioning maneuvers, which means the brain, cervical spine, thorax, abdomen, and pelvis can be imaged to look for any associated bone, internal organ, or brain damage.

Author   Roshdy Guirguis

CT scans are particularly useful at imaging the cervical spine. The whole cervical spine and upper thoracic spine (which is notoriously difficult to x-ray in severely injured people) can be imaged quickly and accurately, while keeping the patient still. The images can be reformatted and viewed in 3-D, giving a more accurate assessment of the state of the cervical vertebrae before removal of the hard collar. CT is also valuable at looking for skull (especially base of skull) fractures and associated intracranial hemorrhage.

Disadvantages and limitations of CT scans

CT scans still emit radiation to obtain images and use more radiation than a single plain x-ray series. Therefore, it must be used sparingly in children and young adults.

Although CT scans are valuable for intracranial, intrathoracic, and intraabdominal soft-tissue injury, they are not particularly helpful with soft-tissue injury around the fractures themselves, for example associated ligament, tendon, or muscle damage. If soft-tissue damage is indicated and needs to be assessed, this may require a more advanced technique—magnetic resonance imaging (MRI).

2.7.4   MRIs

Magnetic resonance imaging is a technique that does not use radiation. MRI utilizes a powerful electromagnet to create a magnetic field that attracts and aligns hydrogen atoms in a patient's tissues. Exposure of tissues to a short pulse of high-frequency radio waves disturbs the alignment of the hydrogen nuclei. As the protons realign, they emit weak radio signals which can be detected by suitably placed receiver coils. Computer analysis of the radio signals allows the spatial distribution of hydrogen atoms and their chemical bonds to be determined, and the data is displayed as a 2-D grey-scale image that can be viewed in any plane (multiplanar capability).
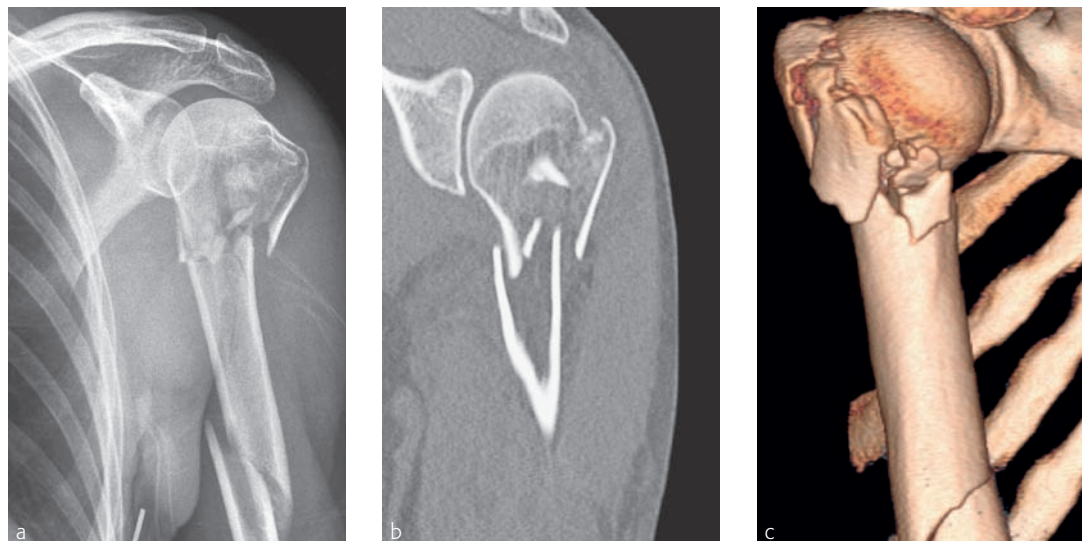
Fig 2.7-2a–c   Multifragmentary segmental fracture of the humeral head and shaft:
a   Plain x-ray.
b   Coronal thin cut CT scan images of bone fragments.
c   3-D volume-rendered images with anteriorly displaced bone fragments before surgery.

An MRIs scan is not only useful in looking for soft-tissue injury but also for identifying bone marrow edema that may be the first and only sign of bony injury which may not be visible on x-rays or CT scans (Fig 2.7-3). Occasionally an occult fracture can be seen on MRI only, which is why MRI is useful for detecting stress fractures.

Advantages and uses of MRI

With MRI, no x-ray radiation is required; thus, the rules that govern x-ray exposure in other modalities do not apply. MRI is safe for use in children and young adults (although there is still doubt over the safety of pregnant women in the first trimester).

Soft-tissue differentiation is excellent, making it possible to distinguish abnormal from normal tissue; it is therefore sensitive for detecting bone marrow edema that may be due to trauma and for undisplaced fractures not seen on other imaging modalities.
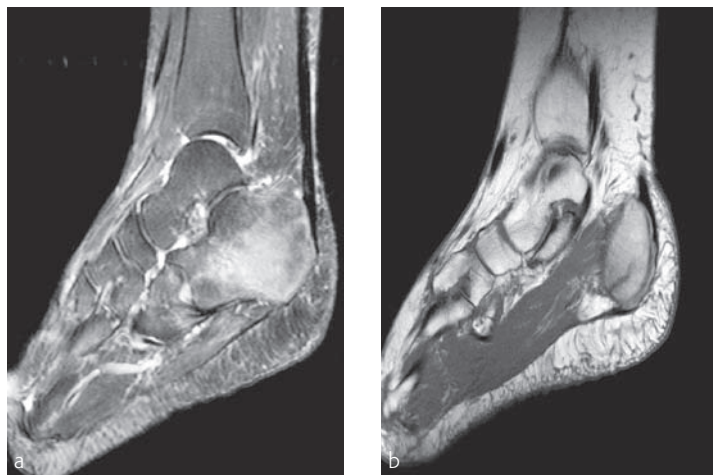
Fig 2.7-3a–b
a   An MRI of a foot with bone marrow edema in calcaneum.
b   Demonstrating a fracture not visible on the plain x-ray.

Disadvantages and limitations of MRI

MRI is generally poor at looking at bone anatomy, and sometimes correlation with plain x-ray is required to evaluate certain fractures. MRI is relatively expensive and is not as widely available as CT. Scanning time is longer than CT (some scans can take 30 minutes or more), therefore patients with considerable pain may find it hard to remain still for the duration of the scan. Movement can severely degrade the quality of the images, occasionally making them useless.

Due to the powerful magnetic fields, some patients, including those with pacemakers and artificial heart valves, are not eligible for an MRI scan. This is also a problem for patients who require general anesthesia for an MRI scan, as standard anesthetic equipment is affected by the strong magnetic field. Moreover, claustrophobic patients may not tolerate lying still within this sometimes noisy scanner which usually surrounds the whole body.

2.7.5   Other diagnostic methods

Scintigraphy

Two other imaging modalities are occasionally used in trauma. The first is nuclear medicine study or bone scan (sometimes known as scintigraphy). This modality uses technetium 99m-labelled tracers that are used to detect areas of high-bone turnover. This study is sensitive and can show abnormal areas of bone which may not be seen on plain x-rays. Bone scans are not specific; infection, tumors, and fractures all have areas of high-bone turnover and hence all show up on a bone scan. Therefore, correlation with other types of imaging is often necessary. Bone scans require a considerable dose of radiation and their use is declining because of the increasing availability (and lack of radiation) of MRIs.

Author   Roshdy Guirguis

Ultrasound

The second modality is ultrasound that uses sound waves to obtain images. Like MRI, it does not use radiation and is a safe, easy, and readily available diagnostic tool. The machines are fairly small, portable, and can be taken to the emergency department, clinic, or operating room. Ultrasound is dependent on an operator. Like MRI, it is useful for examining soft-tissue injury but poor for bone injury. It is, however, increasingly used to look for associated soft-tissue injury around a fracture and also for evidence of hemorrhage within the abdominal cavity of a multiple-injured patient who may be too unstable to be transported to a CT scanner.

2.7.6   Conclusion

In patients with trauma, x-rays are the first-line diagnostic tool. Most bony injuries will be apparent on plain films if one obtains at least two views of the injured area at right angles to each other to maximize the chances of making an accurate assessment of the fracture and its displacement. The x-ray should also include the joint on either side of the fracture.

Multiple-injured patients often require more advanced diagnostic input. CT scans are now widely used to assess associated soft-tissue injury within the chest and abdomen to look for intracranial hemorrhage, and to image the cervical spine and pelvis quickly with minimal movement of the patient. CT is also useful in establishing the exact pattern of complex articular fractures as part of the planning process before surgery.

MRI has now taken over from bone scans to detect early and subtle bone marrow changes that may indicate bony injury. Occult fractures are often diagnosed with MRI, and this modality is particularly useful for displaying associated tendon, ligament, or muscle damage. Ultrasound is also a useful and readily available method of investigating soft-tissue injury.

2.7.7   Further reading

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2.8 Preoperative planning for ORP—the team approach

Author   Steven Schelkun

2.8   Preoperative planning for ORP—the team approach

2.8.1   Introduction

Successful outcome in fracture surgery is directly related to how well the whole operative team plans the surgery. Traditionally, preoperative planning has focused on the preparation of a surgical tactic and a template of the fracture by the surgeon. The execution of this plan, however, requires a closely integrated team approach by the entire operating room (OR) and support staff. In addition, some countries now have regulatory requirements to maximize patient safety that must be included in the preoperative plan. This chapter examines the roles of team members and steps they should take to optimize a surgical procedure.

2.8.2   Why plan?

Benefits derived from preoperative planning include:
- Facilitating the smooth progress of the surgical procedure
- Reducing operative time
- Anticipating technical problems; thus avoiding them
- Exploring alternative surgical plans on paper before surgery rather than in the OR
- Reducing confusion and frustration in the OR
- Ensuring necessary implants and equipment sets are available and ready for use in the OR
- Minimizing opening and subsequent resterilization of unnecessary packs
- Allowing surgical team to mentally prepare and review the case
- Ensuring ancillary staff and equipment (eg, image intensifier, cell saver) are available

A team that routinely practices preoperative planning can attest to the warning that "failing to plan is planning to fail."

Steps in planning

Team preoperative planning is similar to the preflight planning required by the civil aviation community. Every commercial flight starts with a formal flight plan by the pilot in command that is somehow similar to the templating and surgical tactic conducted by the operating surgeon. The flight plan is filed with the appropriate national aviation authority, just as the surgeon must communicate his or her plan and needs to other team members including the anesthesiologist, circulating nurse, surgical scrub technician/nurse, and radiology technician. The pilot also performs an equipment check of the airplane, the instruments, and important systems just as the surgeon and surgical technician/nurse must check to make sure the proper instrument sets and implants are present and fully stocked. Finally, just before take-off the pilot does a final run-up check to ensure all essential systems are functioning properly; just as the surgeon is required at this stage to verbally perform a preoperative "time out" to confirm that the correct procedure is being performed on the right patient; that the correct site and side have been identified and marked on the patient and that appropriate permission is documented in the medical record.

A team approach means that everyone is involved, allowing and encouraging input or questions from any member. This method keeps communication open within the OR, encourages interest and involvement in the case, and establishes that while the surgeon is in charge, every member is critical to a successful operation. Mistakes tend to occur when the team members are not able to voice their concerns.

A surgical preoperative plan should include four steps:

Preoperative planning step	Responsible member
Templating and surgical tactic	Surgeon
Communication within the team	Surgeon and all members
Equipment checklist	Surgeon, surgical technicians/nurses, sterile supply room personnel
Preoperative time-out check	Surgeon and all members

2.8.3 Templating and surgical tactic: simplified "overlay" technique

This step allows the surgeon to understand the fracture by examining the x-rays and computed tomographic (CT) scans. The goal is to understand the number and position of each fracture fragment and then to reconstruct the fracture on paper using the "overlay" technique. Once the fractured bone is reconstructed on tracing paper, a transparent template of the appropriate implant is chosen and traced on the overlay of the reconstructed bone. This allows the surgeon to determine the size and position of the implant and screws.

There are three steps:

Step 1: From a comparison x-ray of the normal extremity, trace the AP and lateral outline of the normal bone (Fig 2.8-1). This determines the 2D length, alignment, and shape of the normal bone onto which the fractured bone can be reconstructed.

Step 2: Overlay the tracing of the normal bone on the x-ray of the injured bone (Fig 2.8-2), and starting from the ends of the bone "reduce" the fractured fragments into the outline of the bone and draw each fracture line and fragment.

Step 3: Overlay the completed tracing of the fractured bone on the appropriate implant (Fig 2.8-3) and draw the outline of the implant (using a different color marker) onto the tracing of the fracture. This allows the surgeon to determine the appropriate
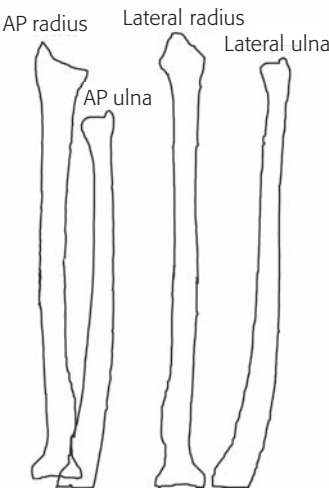
Fig 2.8-1   Outline tracing of the uninjured bone from the opposite extremity.
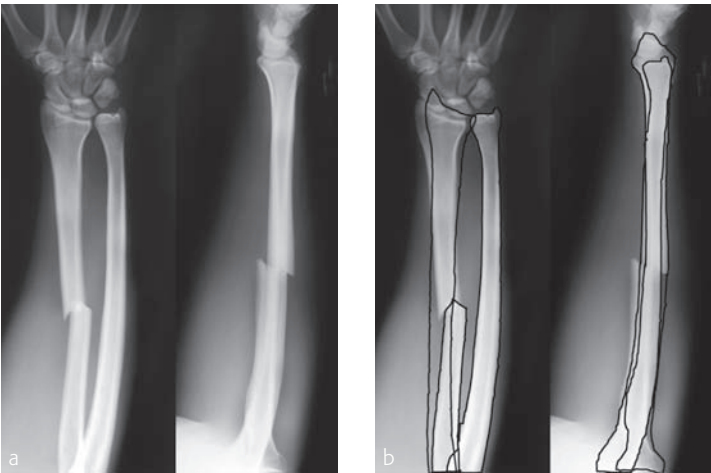
Fig 2.8-2a–b
a   X-ray (AP and lateral) of the fractured forearm.
b   The uninjured bone outline is placed over the x-rays and the fracture lines are drawn.

Author   Steven Schelkun

size and position of the implant relative to the fracture fragments and screw holes on the plate (Fig 2.8-4). It is important that the implant templates have the same magnification as those of the x-rays.

Next, the surgeon plans the procedure and writes each step of the surgical tactic. This clarifies the surgeon's thoughts and is an essential part of communicating with other team members who in turn use the information for their planning. A tactic should include patient position, type of OR table required, use of a tourniquet,

use of prophylactic antibiotics, and equipment required, particularly any unusual implants. Then follows a step-by-step guide to the procedure detailing surgical approach, significant anatomical structures to identify and avoid, reduction techniques to be used, and position of implant. The surgeon should convey relevant information to the surgical team so that they can anticipate the need for drains, closure suture, dressing material, and splints. The surgical tactic can be displayed on the x-ray view box next to the template and equipment list.

3.5 mm LC-DCP
[423. series]

a

b

Surgical tactic

Equipment:
Titanium small fragment set
6–8 hole 3.5 mm LC-DCP
Small battery drill
Hand table
Tourniquet
Fluoroscan

Position:
Supine

Approach:
Dorsal (Thompson)
Protect radial nerve
Restore radial bow
Contour plate (neutralization)
Lag screw outside plate

Check distal radioulnar joint

Drain

Closure

Splint

Fig 2.8-3a–b
a   Transparent template of a small-fragment LC-DCP 3.5.
b   The provisional position of the plate is being drawn onto the reduced bone.

Fig 2.8-4   Fixation screws are drawn and a surgical tactic developed.

Digital preoperative planning

As more hospitals adopt digital imaging, the availability of hard copy x-rays for preoperative planning is becoming less common. Digital preoperative planning programs are becoming more popular and can incorporate all elements of a good preoperative plan. These can then be submitted to the OR electronically to save time (Fig 2.8-5).

Fig 2.8-5   A digital preoperative plan.

2.8.4   Communication

Communication is the most vital feature of a surgical procedure, and is the one that contributes most to a successful outcome.

A formal-planning process is designed to ensure surgeons communicate their exact needs to the OR team. It is also crucial that they in turn communicate their needs, ensuring that appropriately experienced staff is scheduled to the OR, that the necessary implants and instruments are available, and that other special equipment required, such as a specialized operating table or a blood reinfusion system is in place.

Communication should flow in both directions and when staff is unclear on any detail, or has any questions, concerns, or suggestions these must be discussed with the surgeon. If each member is proactive in preparing, anticipating, and communicating, it is much less likely that a detail will be overlooked and more likely that the operation will run smoothly.

Equipment checklist

While standard surgeon preference cards work well for routine cases, more complex fracture surgery has unique and individual requirements for each fracture. In such cases it is extremely helpful if the surgeon provides an equipment, instrument, and implant list of the sets that will or may be required. Having the proper equipment actually in the OR can save valuable minutes during the procedure as well as eliminate the frustration and confusion that frequently results from a poorly planned and poorly communicated surgical procedure. The author's equipment list is illustrated in Figure 2.8-6.

Preoperative time-out check

Making sure that the correct operation is being done on the correct side of the right patient is vital to the whole surgical team. Mistakes tend to happen when cutting corners. Most hospitals now mandate a "pause" or "time-out check" before initiating the

Author   Steven Schelkun

Preoperative planning instrument and equipment list for Dr Schelkun

Patient name:

Date of surgery:

Procedure:

Position of patient:

- Supine
- Prone
- Lateral
- Beach chair

- Hip grip positioner
- Bean bag
- Axillary roll
- Foam headrest

- Bump under hip
- Roll under shoulder

Table:

- Regular
- Fracture table
- Hand table

- Radiolucent extension
- Spine table
- Sterile finger traps and weights

- Blue foam femoral pillow
- Blue foam tibia cushion
- Foam elbow cushion

X-ray:

- Image intensifier
- C-arm
- Portable

Drape pack:

- Extremity pack
- Extremity drape
- Bilateral extremity drape

- Shoulder pack
- Hip pack
- Isolation drape

- Adhesive drape
- Tourniquet
- Sterile tourniquet

Primary instrument set:

- Hand and foot
- Arthroscopy set
- Major bone set

- Plastics set
- Minor bone set
- Hip set

- Micro instruments
- Bone graft set-up on stand

Power tools:

- Small battery power drive set
- Large battery power drive set
- Radiolucent right angle drive for small battery drill
- Oscillating attachment for small battery drill
- Hihg-speed burr
- Oscillating saw

- Micro-air saw

Special equipment:

- K-wires
- Skin hooks
- Probe
- Small knife handle
- Blades: #_____

- Osteotomes, standard
- Osteotomes, small
- Heavy pin (bolt) cutters
- Small-hand retractors
- Currettes, large
- Currettes, small

- Microscope
- Lead hand

- Hohmann retractors

Dressing:

- 4x4 gauze
- 2x2 gauze
- Fluffs
- Soft roll
- ABD

- Bias cut stockinnette
- All cotton elastic wrap
- Foam tape
- Iodine ointment
- Cast cart
- Cradle sling

- Suction drain

Individual instruments:

- Soft tissue washers
- Wire mounts
- Calcaneal plates

Other:

Fig 2.8-6   Example of a preoperative planning instrument and equipment list used to communicate with team members.

surgical procedure. It was originally intended to ensure patient safety by identifying the correct patient, surgical side, and procedure. This is frequently a brief and cursory check.

One way of improving this system is to have a preoperative check-off list similar to the checklists that are required and used by the aviation industry. The list used by the author (Fig 2.8-7) is preprinted on a clipboard. After the patient is positioned on the table and all team members have had a chance to complete their

Preoperative planning step Responsible member
Patient name?
Surgical side?
Procedure?
Informed consent signed by surgeon?
Operative consent signed by patient/guardian?
Allergies?
Antibiotics given?
Pressure points padded?
Axillary roll (if lateral position)
Safety strap?
X-rays/MRI up?—name correct and most recent ones?
Instrument list checked?
Procedure briefing with team
Questions/concerns by anyone in the room?
Music
Inject portals
Scrub time

Fig 2.8-7   Example of a time-out check-off list.

individual responsibilities, the surgeon calls for a "time out." One member identifies the patient by reading the name and hospital number from the armband. This is matched and checked with the chart and anesthesia records. The surgeon then goes down the list and gets a verbal response from a member with each item on the list. The entire process takes less than 30 seconds and not only covers every important patient safety item but also establishes a line of communication within the OR that sets the tone for the procedure. It also allows for questions, comments, or concerns by any member to be raised before initiating the procedure. The completion of the checklist is the final official event before the surgeon leaves the OR to scrub in.

2.8.5   Conclusion

Successful fracture surgery is a complex chain of events that involves many key personnel in the surgical department. Preparation and communication by every member is essential for a smoothly run operation. If surgeons fail to plan properly, they are likely to spend longer doing a less successful operation than if they invest some time and effort before starting in thinking what it is they are intending to do, thus not running the risk of finding a vital implant or piece of equipment is not available.

Once the plan is handed over to the OR team, a member who fails to communicate or complete the assigned task risks jeopardizing the surgical procedure, at best by causing delay and frustration, and at worst compromising patient outcome and safety.

Author   Steven Schelkun

2.8.6   Further reading

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2.9   Multiple fractures/polytrauma patients

Author   Peter V Giannoudis

2.9   Multiple fractures/polytrauma patients

2.9.1   Introduction

Trauma is the fourth most common cause of death for all age groups and the most common cause of death for young adults. Polytrauma is the subgroup of injured patients who have sustained injuries to at least two of the following six-body regions:

- head, neck, and cervical spine
- face
- chest including thoracic spine
- abdomen including lumbar spine
- limbs including bony pelvis
- skin

The cumulative severity of this trauma load on the patient's anatomy and physiology is often expressed as an injury severity score (ISS) of 16 or above and represents 15–20% of the overall trauma population. The ISS is calculated from the degree of injury severity to the three most severely injured body regions. Polytrauma patients have significantly greater mortality and morbidity and require complex multidiscipline medical management, prolonged hospitalization, rehabilitation, and recovery periods. The social and economical implications for the patient, his/her family, and society in general, are immense.

The pathway of clinical interventions of patients with multiple injuries is complex and involves input from a variety of medical disciplines. The different steps of the pathway are as follows: initial management at the scene of the injury and transport to a medical facility, resuscitation room, diagnostics (radiological investigations), operating room, intensive care unit, ward care, in-hospital rehabilitation, and discharge home (Fig 2.9-1). The clinical management of the patient, however, continues even after hospital discharge as many patients require additional rehabilitation and further reconstructive procedures involving considerable input for a substantial period. The clinical input and the decision-making process in each step of this pathway can be critical for minimizing long-term morbidity and mortality.

Pathway in the care of polytrauma patients

Scene of injury

↓

Transport

↓

Resuscitation room

↓

Operating room

↓

Intensive care unit (ICU)

↓

Ward care—nursing

↓

Rehabilitation

↓

Return to community
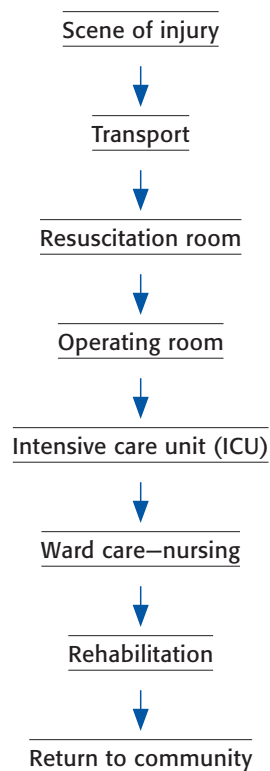
Fig 2.9-1   Pathway in the care of polytrauma patients.

2.9.2 Initial assessment—resuscitation room

The prehospital care of the multiple-injury patient is outside the scope of this chapter and varies considerably from country to country. Once in hospital, the initial assessment of the injured patient must have a stepwise approach with planned diagnostic and operative tactics to avoid mistakes that could affect the patient's prognosis. The clinical course of the patient can change rapidly and management plans must be adapted accordingly.

The advanced trauma life support (ATLS) course has had a great impact on providing a common language for all who care for the injured patient. It has established an organized and systematic approach for the evaluation and treatment of patients and has had a positive influence on the care provided worldwide. Details of the ATLS protocol are not presented here, but to summarize it comprises a primary survey to rapidly diagnose and treat immediate life-threatening conditions, followed by a careful secondary survey to ensure all of the patient's injuries are identified and subsequently treated.

2.9.3 Immediate life-threatening conditions of the multiple-injury patient

- Airway obstruction or injury and asphyxia (eg, laryngeal trauma)
- Tension pneumothorax or hemothorax
- Open thoracic injury and flail chest
- Cardiac tamponade
- Massive internal or external hemorrhage

The routine of A (airway with cervical spine control), B (breathing), C (circulation), D (disability, a brief neurological assessment), and E (exposure of whole patient) is designed to assess and treat any life-threatening conditions, and to avoid obvious or dramatic but less dangerous secondary lesions distracting the resuscitation team from identifying hidden but immediately life-threatening problems.

Once life-threatening problems are diagnosed and treated, a full systematic head-to-toe "secondary survey" of the patient's condition must be undertaken. This may need to be delayed until after initial surgery has been performed and the patient is stable, but it should never be omitted. Comparatively minor injuries, if missed, may receive suboptimal treatment causing long-term loss of function and considerable morbidity.

The tertiary survey consists of a repeated head-to-toe evaluation of the patient and provides another opportunity to evaluate any newly discovered physical findings and diagnose any missed injuries. It also involves daily laboratory data and new radiological examinations in the form of plain x-rays, computed tomography (CT), or magnetic resonance imaging (MRI) with a low threshold for imaging any unexplained or suspicious clinical signs. Repeated thorough physical examination is vital and contributes favorably to the patient's long-term outcome.

2.9.4 Definition of the patient's condition

Following the initial ATLS assessment and the primary interventions, the physiological condition of the patient must be placed into one of four categories to direct the subsequent treatment protocol. This assessment is based on the overall injury severity, the presence of specific injuries, and hemodynamic status. The four categories are:

- Stable
- Borderline
- Unstable
- In extremis

Author   Peter V Giannoudis

For the physician to appropriately categorize the patient, he/she has to assess whether the patient has been adequately resuscitated.

Stable

These patients respond to initial therapy and are hemodynamically stable. They have no immediate life-threatening injuries and there are no signs of physiological disturbance, such as coagulopathy or respiratory distress. They have normal acid-base status, meaning they do not have hidden underperfusion of any vital organ.

Borderline

Borderline patients have stabilized in response to initial resuscitative attempts but have clinical features or combinations of injuries which have been associated with poor outcome and put them at risk of rapid deterioration.

Factors that increase risk of poor outcome or sudden deterioration

- ISS > 40
- Hypothermia < 35° C
- Initial mean pulmonary arterial pressure > 24 mm Hg or > 6 mm Hg rise in pulmonary artery pressure during intramedullary nailing or other operative intervention
- Multiple injuries (ISS > 20) in association with thoracic trauma
- Multiple injuries in association with severe abdominal or pelvic injury and hemorrhagic shock at presentation (systolic blood pressure <90 mm Hg)
- X-ray evidence of pulmonary contusion
- Patients with bilateral femoral fractures
- Patients with moderate or severe head injuries

Unstable

Despite initial intervention, patients who remain hemodynamically unstable are at increased risk of rapid deterioration, subsequent multiple organ failure, and death. Treatment in these cases should include rapid life-saving surgery only as absolutely necessary and timely transfer to the intensive care unit for further stabilization and monitoring. Whenever possible, temporary stabilization of fractures using external fixation, hemorrhage control, and exteriorization of gastrointestinal tract injuries is advocated.

In extremis

These patients frequently have ongoing uncontrolled blood loss. They are close to death, having suffered severe injuries and they remain physiologically unstable despite ongoing resuscitative efforts. They are usually suffering the effects of a "deadly triad" of hypothermia, acidosis, and coagulopathy. A damage-control approach is certainly advocated, although only absolutely life-saving procedures are attempted in order not to drive this process further. The patient should then be transferred directly to intensive care for invasive monitoring and advanced hematological, pulmonary, and cardiovascular support. Orthopaedic injuries can be stabilized rapidly in the emergency department or intensive care unit using external fixation, and this should not delay other therapy. Any reconstructive surgery is delayed and can be performed if the patient survives.

2.9.5   Operating room—surgical strategy

The two surgical strategies that have evolved over the years are the early total care approach (ETC) and the damage-control orthopaedics concept (DCO). The ETC approach was adopted in the 1980s and implies that all injuries of the patient should be stabilized early, within 24 hours of injury, and during the same operative setting. However, it became clear that not all patients would benefit from this approach. In the early 1990s a variety of unexpected complications related to early stabilization of fractures of long bones were reported. It was then realized that ETC was not appropriate for all multiple-injury patients as an increased incidence of adult respiratory distress syndrome (ARDS) and multiple organ dysfunction syndrome (MODS) was observed in some of the most severely injured. An increased understanding of the pathophysiological mechanisms governing trauma and the

immunoinflammatory response to injury provided an understanding why these unexpected complications were happening.

The initial traumatic insult (or "first hit") stimulates the immune system leading to a state of systematic inflammation. The magnitude of this process, which is called systemic inflammatory response syndrome (SIRS), correlates to the degree of injury sustained. This first-hit phenomenon, if it becomes overactive or exaggerated, can cause remote organ injury and the patient can progress rapidly to ARDS and MODS.

In addition, it is now clear that surgery performed in the first 3–4 days after the initial trauma, known as the "second-hit" phenomenon, increases the burden on the biological reserve of the patient already compromised by the magnitude of the first hit. If the magnitude of the second hit (ie, surgery) exceeds the regulatory mechanisms of homeostasis, the patient enters a malignant inflammatory state and again rapidly progresses to ARDS or MODS with its associated increased risk of mortality.

Besides the impact of the first- and second-hit phenomena, it is now accepted that individual biological responses vary as they are regulated by the genetic make-up of the patient and some can withstand more injury than others before developing SIRS.

Clearly, too much surgery in a severely injured patient can precipitate SIRS and MODS and should be avoided; thus, in at-risk individuals a DCO strategy must be adopted to minimize the second hit and reduce this risk.

The sequence of the clinical course of the patient being treated with the damage-control principle is shown in Figure 2.9-2.

In general the severity of the injuries sustained and the clinical condition of the patient are major factors governing which line of treatment should be implemented in patients with polytrauma.

For the stable patient, the ETC approach is still valid and definitive fracture stabilization can be performed safely within 24 hours of injury. For the borderline patient, ETC may still be used with caution and the surgeon and anesthesiologist will have to be alert to observing potential physiological changes during surgery. There should not be any hesitation to converting to the damage-control approach at any time throughout the procedure if the clinical condition of the patient deteriorates. For the patient who is unstable or in an extremis situation, the damage-control approach is recommended from the start (Fig 2.9-3). Any surgical intervention here must be considered as life-saving and should be

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Patient with multiple injuries in an unstable condition or in extremis

Stage 1 ↓ Operating room

Temporary stabilization of fractures with external fixator—cavity decompression—maintenance CPP > 70 mm Hg

Stage 2 ↓ Intensive care

Resuscitation—correction of hypothermia and coagulation disturbances—ICP monitoring

Stage 3 ↓ Operating room

Operating room (after day 4) definitive stabilization of fractures

Fig 2.9-2   Sequence of damage-control surgery. CPP indicates cerebral perfusion pressure; ICP, intracranial pressure.

Author   Peter V Giannoudis

quick and well performed. In the presence of severe head injuries, the damage-control approach is also advocated, as brain injury may lead to further morbidity and disability. If the patient survives, definitive fixation of fractures with removal of any temporary external fixation can be done once the condition has stabilized, and the risk of developing SIRS has receded, at least 4–5 days after initial injury.

Trauma—first hit

↓

Resuscitation

↓

Patient condition

↓   ↓   ↓   ↓

Stable   Borderline   Unstable   In extremis

↓   ↓   ↓   ↓

Type of surgical intervention?
Consider the impact of second hit

↓   ↓   ↓   ↓

Early total care ⟶ Damage-control surgery
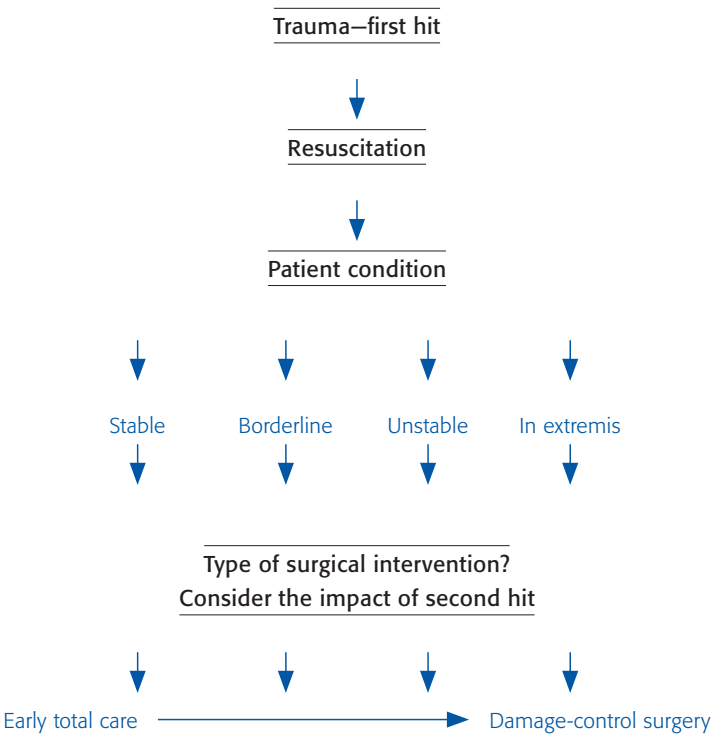
Fig 2.9-3   Treatment strategy based on a patient's clinical condition.

2.9.6   Intensive care unit—management

In the intensive care unit, patients with multiple injuries are subjected to intense physiological monitoring and receive supportive care of all organ dysfunctions. The two major posttraumatic complications managed are ARDS and MODS. The overall incidence of MODS remains high and ranges between 21–30% despite all advancements that have recently been made.

2.9.7   Rehabilitation

In patients with multiple injuries the rehabilitation process starts in intensive care and requires close collaboration among the surgeon, intensivist, and the physical therapist. Regular mobilization of all main joints should be performed and should be part of a standardized rehabilitation program to maintain joint mobility, and prevent osteoporosis induced by immobility.

2.9.8   Conclusion

The management of the multiple-injury patient is multidisciplinary. Initially, the ATLS protocol should be used to assess and treat the patient when there are immediate life-threatening injuries. Thereafter the condition of the patient has to be continually assessed and a decision made as to stability and whether or not to be managed by an ETS or DCO strategy. There is no doubt that as our understanding of the pathophysiology of multiple injuries improves, the way we manage patients will continue to evolve.

2.9.9 Further reading

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2.10 Reduction techniques

Author   Paul Szypryt

2.10   Reduction techniques

2.10.1   Definition of fracture reduction

Fracture reduction is the exact or near restoration of the correct position of fracture fragments, in other words restoring the anatomical shape of a broken bone. In shaft fractures that do not involve the joint surface reduction involves the restoration of the correct length, axis, and rotation of the fractured bone but does not necessarily involve putting all the bone framents back into their anatomical position (functional reduction). To do so might involve further damage to the blood supply of the bone fragments and their soft-tissue attachments leading to problems with fracture healing. In fractures involving a joint, perfect reduction of the joint surface and restoration of the mechanical axis of the limb is necessary for normal joint function (anatomical reduction). Because fractures of the shaft of the radius and ulna require perfect reduction of the fractures to achieve normal function, fractures of these bones are regarded as joint fractures when considering reduction requirements and technique.

Reduction usually involves reversal of the deforming forces that led to the displacement of the bony fragments. It is important to be highly vigilant at all times to avoid further damage to both the fracture fragments and the surrounding soft-tissue envelope.

There are two types of techniques that can be used to achieve fracture reduction.

2.10.2   Direct reduction

Direct reduction, as its name implies, involves the direct visualization and manipulation of the fracture fragments with hands or instruments through limited surgical exposure. This technique is particularly relevant in simple (two-part) diaphyseal fractures when closed reduction has failed, and in intraarticular fractures where perfect restoration of joint congruity is critical to restore function and limit disability.

Assessment of direct reduction

This is accomplished by direct observation of the fracture fragments in the surgical field, allowing assessment of the bone ends to determine if anatomical reconstruction has been achieved (like matching pieces of a puzzle).

The fracture ends are usually controlled by reduction forceps and/or bone clamps (Figs 2.10-1 and 2.10-2).

a

b
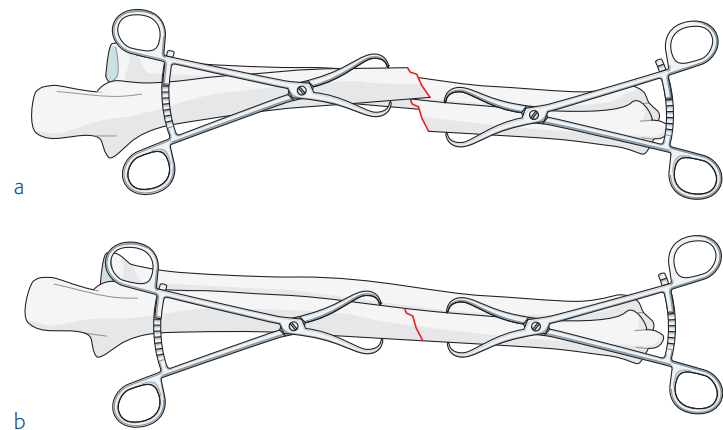
Fig 2.10-1a–b   Direct manual reduction using two-pointed reduction forceps.
a   Each main fragment is held with a pointed reduction forceps.
b   Reduction is achieved by manual traction, while correct rotation and axial alignment can be controlled with the forceps.

Sometimes a plate precontoured to fit the anatomy of the bone can be used to aid the reduction. An example of this technique is the antiglide plate. Tightening a precontoured plate onto the bone reduces the fracture (Figs 2.10-3 and 2.10-4). Another example of the use of a plate to achieve reduction is the "push-pull" technique. The plate is precontoured to fit the bone. It is attached to one side of the fracture. A screw is inserted approximately 1–2 cm from the end of the plate. A bone spreader is then used to achieve distraction of the fracture. Once reduction has been obtained a Verbrugge clamp can be used to achieve compression at the fracture site (Fig 2.10-4).

Fig 2.10-3a–c   Indirect reduction with a plate functioning in antiglide mode.
a   Posteriorly displaced fracture (type B) of the lateral malleolus.
b   A 4-hole one-third tubular plate is fixed posterior to the proximal fragment.
c   Tightening of the proximal screw forces the distal fragment into a reduced position where it is firmly held by the plate. A second screw adds to the stability.

Fig 2.10-2a–c   Direct reduction of an oblique fracture using one pointed reduction forceps.
a   Unreduced fracture.
b   Both fragments are held with a slightly tilted reduction forceps.
c   By gently rotating and tightening the forceps the fracture is reduced.
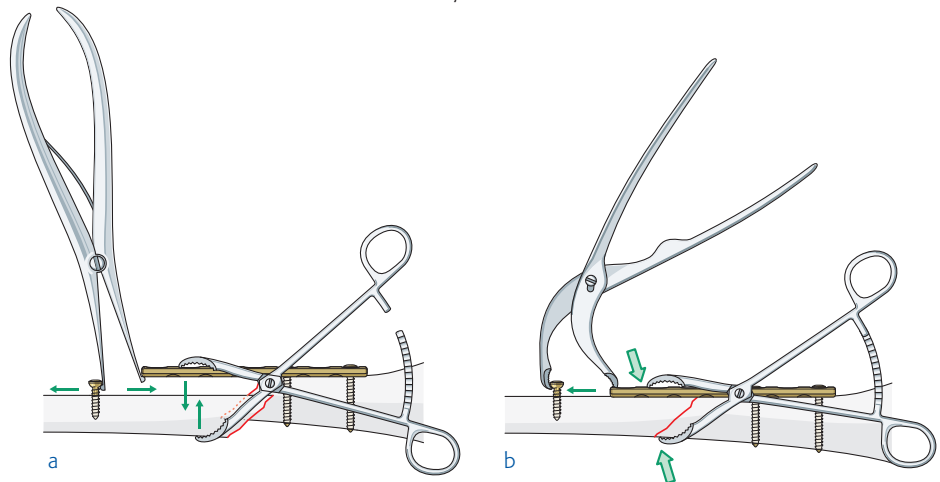
Fig 2.10-4a–b   Push-pull technique.
a   A bone spreader placed between the end of a plate and an independent screw can be used to distract or push apart the fracture to facilitate reduction.
b   Using the same screw, interfragmentary compression can then be obtained by pulling the plate end toward the screw.

Author   Paul Szypryt

It is essential that intraoperative x-rays or image intensifier views in two planes, at 90º to each other, are obtained to assess not only the quality of reduction of the fracture but also to confirm reduction in that part of the bone not directly seen. Imaging is also important to ensure that the overall length and alignment has been restored.

Problems associated with this type of reduction are:

- First, it involves direct exposure of the fracture via surgical incisions—often through a damaged soft-tissue envelope.
- Second, in such circumstances overenthusiastic surgical exposure can further damage the blood supply of the skin flaps and bone ends.
- Third, direct reduction involves handling of the fracture fragments using bone clamps, which can further damage the delicate blood supply to the fracture fragments and periosteum.

To avoid these problems if open reduction is deemed the best option to enable adequate treatment of a certain fracture type, the following are mandatory:

- Delay surgery until soft tissues are healthy. This may take between 5 days for fracture with moderate soft-tissue swelling and 3 weeks for fractures with severe soft-tissue damage, especially pilon fractures.
- Careful planning of surgical incisions to optimize exposure but minimize soft-tissue damage.
- Careful handling of soft tissues and bone fragments throughout the operation.

This type of reduction is usually accompanied by fixation techniques producing absolute stability leading to direct bone healing. It is a technique most suited to simple diaphyseal/metaphyseal fractures and intraarticular fractures when accurate reduction and early movement are important to improve outcome (Figs 2.10-5 and 2.10-6).
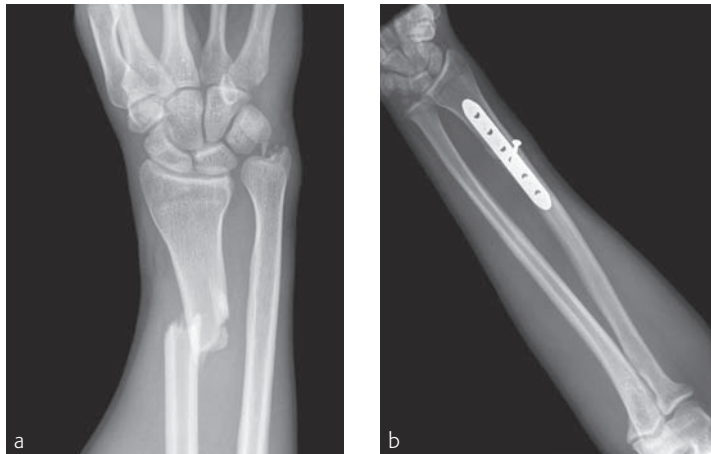
Fig 2.10-5a–b
a   Galleazi fracture of the forearm.
b   Fracture anatomically reduced and fixed with a lag scew and a protection plate to provide absolute stability.
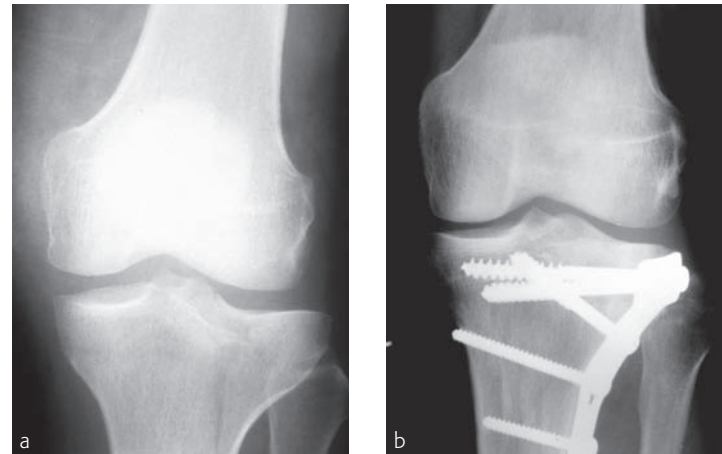
Fig 2.10-6a–b
a   Fracture of the lateral tibial plateau. Note the depression of the articular surface of the joint.
b   Anatomical reduction and rigid fixation achieved with a buttress plate and lag screws.

Direct reduction is not an appropriate treatment for multifragmentary fractures of the diaphysis and metaphysis because of the damage it does of the blood supply to the bone fragments.

2.10.3 Indirect reduction

Indirect reduction is defined as reduction of fracture fragments by applying corrective forces at a distance from the fracture, by distraction or other means. The fracture site is not exposed and the bone ends are not seen directly (Fig 2.10-7). One major advantage of indirect reduction is to minimize the amount of soft-tissue damage incurred by surgical intervention.
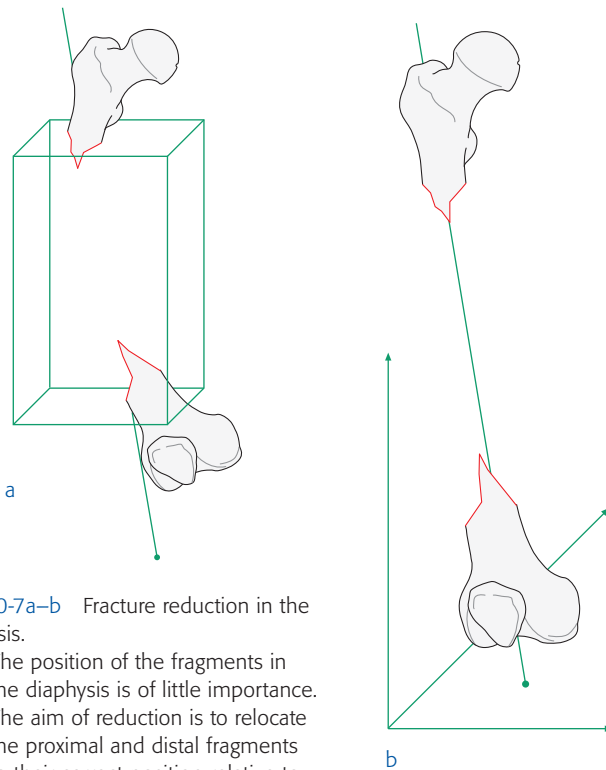
Fig 2.10-7a–b   Fracture reduction in the diaphysis.
a   The position of the fragments in the diaphysis is of little importance.
b   The aim of reduction is to relocate the proximal and distal fragments to their correct position relative to each other.

The types of fracture most likely to benefit from this technique are multifragmentary fractures of the diaphysis and metaphysis and simple articular fractures; as long as the soft-tissue attachment is preserved and closed reduction can be easily achieved by ligamentotaxis.

Depressed multifragmentary intraarticular fragments cannot be reduced anatomically by ligamentotaxis alone because the depressed bone fragments do not have any soft-tissue attachments.

Precise anatomical reduction of all bony fragments in extraarticular multifragmentary fractures is unnecessary and likely to have serious damaging effects on fracture healing, producing an increased risk of devascularization, delayed union, nonunion, infection, and implant failure as a consequence of overenthusiastic surgery.

Following indirect reduction the fracture should usually be stabilized using a minimally invasive technique so as to restrict further damage to soft tissues and preserve blood supply to the fracture site.

Assessment of indirect reduction
Because fracture ends are not exposed or seen directly, assessment of adequate reduction can be difficult and not only relies on the operating surgeon being able to check the reduction using an image intensifier but also to assess the position of the main proximal and distal fragments in relation to the long axis of the limb, thereby ensuring length, alignment, and rotation have been restored. Comparison with the opposite uninjured side is often useful.

Problems are frequently encountered as the other limb does not always provide an adequate comparison, and the field of view with an image intensifier can be restricted. The axis of the limb can be assessed by the following technique. A diathermy (Bovey) cable is positioned over the center of the femoral head using the image intensifier. The lower end of the same cable is positioned over the center of the ankle joint. If the correct axis of the limb

Author   Paul Szypryt

has been restored an image intensifier of the knee joint will show the cable passing over the center of the joint (Fig 2.10-8).

Careful preoperative planning is essential for all types of surgery but is particularly important when using indirect reduction and minimally invasive techniques.

Step 1

Step 2

Step 3
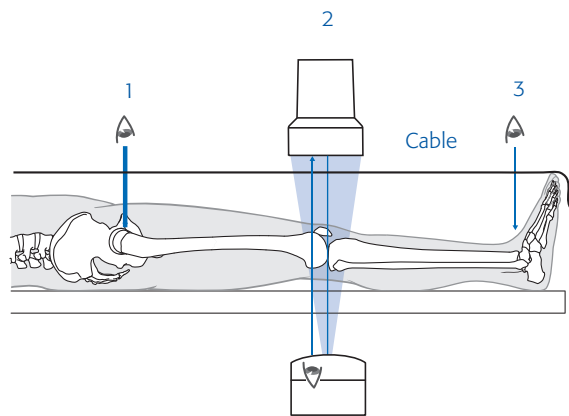
Fig 2.10-8   Cable techniques for checking alignment in the coronal plane: The knee is fully extended and the patella must face anterior.
Step 1 With the image intensifier beam strictly vertical, the center of the femoral head is centered on the screen. With a pen the center of the femoral head is marked on the patient's skin.
Step 2 When the knee joint is viewed, the cable should run centrally. Any deviation of the projected electrocautery cable from the center of the knee joint indicates axial deviation in the coronal plane.
Step 3 In a similar way the center of the ankle joint is marked. An assistant now spans the cable of the electrocautery between these two landmarks.
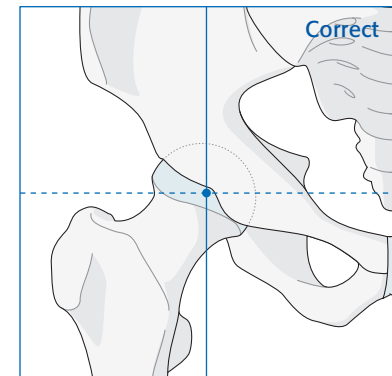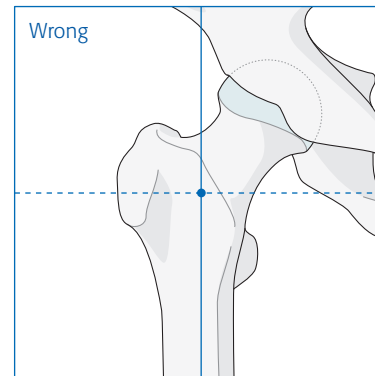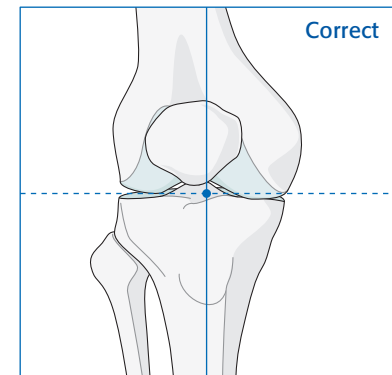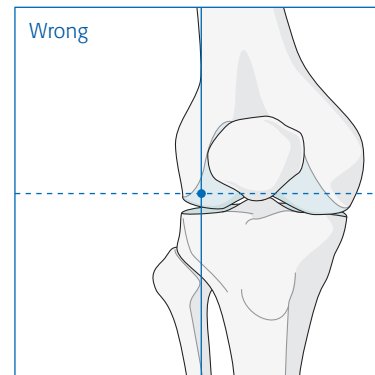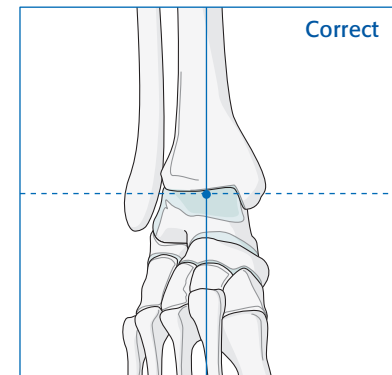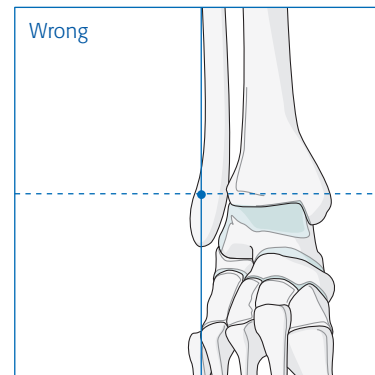
Traction is the most important method of indirect fracture reduction. It is normally applied in the long axis of the limb and is designed to overcome the deforming forces of gravity and/or the pull of the muscles on the main fracture fragments. It can be provided by manual traction, eg, a surgical assistant, or by external mechanical means using a traction table, finger traps, or a specific device such as an external fixator or universal distractor (Fig 2.10-9).

Fine tuning of the reduction can be further achieved with the precontoured surgical implant used to treat the fracture, such as an intramedullary nail or extramedullary bridging plate. Additionally, Schanz screws can be inserted into one or both main fragments outside the zone of injury and used as joysticks to assist with complex or difficult reductions (Fig 2.10-10). These techniques enable the surgeon to exert a more direct influence on the fracture reduction without further compromising the blood supply to the bone ends.

Fig 2.10-9   Indirect reduction of the femoral shaft using a universal distractor.
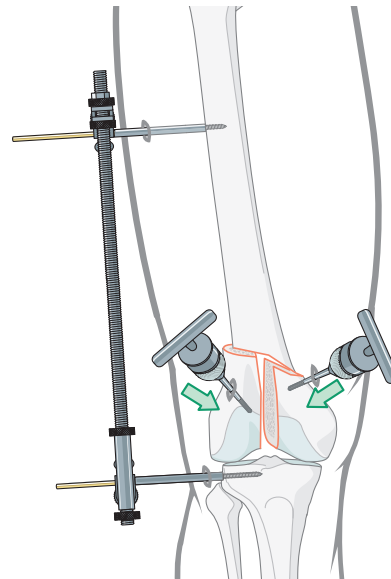
Fig 2.10-10   Using two Schanz screws as joysticks to aid indirect reduction combined with a universal distractor.

Author   Paul Szypryt

Indirect reduction is usually accompanied by fixation techniques which produce relative stability (ie, splinting); as long as the blood supply is preserved and movement is controlled and not excessive. In such cases one would expect the fracture to heal by indirect healing and callus formation. No bone graft or graft substitute is usually required (Figs 2.10-11 and 2.10-12).

Fig 2.10-11a–b
a   Multifragmentary fracture of the distal femoral shaft.
b   After intramedullary nailing, relative stability is achieved and the
      fracture healed with callus.

Fig 2.10-12a–b
a   Multifragmentary fracture of the distal tibia.
b   Healing with callus after fixation with a bridging plate provides relative
      stability at the fracture site.

2.10.4 Conclusion

Selecting the most appropriate form of reduction for a particular fracture is a key step in its management and is a vital part of the fracture-planning process (Tab 2.10-1).

Simple diaphyseal and most intraarticular fractures are usually managed by direct reduction followed by absolutely stable fixation, while multifragmentary diaphyseal fractures are better managed by closed reduction and a relatively stable method of fixation so as to minimize disruption of blood supply to the fragments.

	Direct reduction	Indirect reduction	Type of stability	Bone healing
Displaced complex articular fractures	++++	+	Absolute	Direct (no callus)
Simple diaphyseal fractures (except femur and tibia)	+++	+	Absolute	Direct (no callus)
Displaced simple articular fractures	++	++	Absolute	Direct (no callus)
Multifragmentary fractures, diaphysis and metaphysis	–	+++++	Relative	Indirect (callus)
Risk of malreduction (especially rotation)	+	+++		
Risk of devascularization	+++	+		

Tab 2.10-1   Summary of direct vs indirect reduction.

2.10.5 Further reading

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2.11 Minimally invasive techniques

Author   Theerachai Apivatthakakul

2.11   Minimally invasive techniques

2.11.1   Introduction

The concept of minimally invasive osteosynthesis (MIO) is not new. Closed intramedullary nailing, the percutaneous fixation of fractures using screws and K-wires, the application of external fixators, and use of bridging plates have all been performed using minimally invasive techniques for many years. However recent developments in implants, particularly the introduction of locking plates, have made MIO much more widely applicable than has been the case in the past.

The increasing trend toward indirect reduction of a fracture under image intensifier control, preservation of the fracture hematoma, and minimizing soft-tissue damage is logical since we know that the most important factor in achieving fracture union is preservation of the blood supply to the fracture fragments and adjacent soft tissues. It is, however, important to recognize that a small incision is not the same as a well-performed and planned operation, and that poorly performed MIO will have a much worse outcome than well-performed surgery done through a much larger incision.

This chapter looks at trends in the use of MIO, in particular minimally invasive plate osteosynthesis (MIPO) and some of the newer techniques and instruments that have been developed to facilitate it.

2.11.2   Indications for minimally invasive osteosynthesis (MIO)

Fractures can be broadly divided into those which require anatomical reduction of the fracture fragments and fixation with implants which achieve absolute stability and the rest, most of which can be managed by restoration of the correct length, axis, and rotation. These fractures do not require strict anatomical reduction of all fracture fragments. These fractures are then usually fixed with implants which provide relative stability, allowing them to heal with callus formation.

Whether and how an open or closed articular fracture can be accurately reduced is largely dependent on the complexity of the fracture. Simple fractures may be reduced and fixed with percutaneous lag screws using a minimally invasive technique. This always needs to be done under image intensifier guidance, and sometimes augmented by arthroscopy, particularly in the knee joint. Complex articular fractures almost always need accurate reduction under direct vision before fixation.

In diaphyseal fractures, as long as the joint at each end of the bone is correctly rotated and aligned and the bone has the correct length, the exact position of the fracture fragments is not as important as maintaining a good blood supply to the bone. Recognition of this fact has been responsible for the trend away from open plate fixation of shaft fractures toward the use of locked intramedullary nails, external fixation, and bridge plating.

From the mid-1990s surgeons began to combine the two concepts of fracture reduction in fractures that had both intraarticular and extraarticular components, reducing and fixing the articular portion under direct vision, while using minimally invasive bridge plating for the extraarticular component, leaving this segment of the fracture unexposed. As the concept has become increasingly popularized, implants that make it easier, such as locking and then contoured locking plates, have been developed together with appropriate instrumentation.

Advantages of MIO

- Smaller incisions
- Less blood loss
- Preserves blood supply to bone
- Less soft-tissue damage
- Facilitates rehabilitation
- Achieves better cosmetic results
- Possible reduction in infection rate

Disadvantages of MIO

- Fracture not seen
- Technically more difficult
- Nerves and blood vessels can be at risk
- Requires image intensification
- Requires special instrumentation
- Steep learning curve
- Easy to do badly

Preoperative planning

Good preoperative planning is mandatory for all MIO. A plan and tactic for the operation, including the implants and instruments required, must be provided by the surgeon. The tactic should include implant selection, patient position and approach, and the steps of the operation (see chapter 2.8).

2.11.3 Minimally invasive plate osteosynthesis (MIPO)

MIPO is not a new technique; surgeons have long recognized the benefit of inserting conventional plates as bridging plates through small incisions outside the zone of injury after reducing the fracture by indirect methods. This technique has gained acceptance both because of the appreciation that minimizing soft-tissue damage preserves blood supply to the injured bone, and because it is possible with conventional plates. The introduction of locking plates has widened the scope and range of its application especially in osteoporotic bone.

Some surgical tips for MIPO are presented here. These are intended to be generally applicable. Information on how to use the technique for specific fractures are detailed and illustrated in section 3 of this book.

Planning positioning and approach

Detailed planning of any MIPO procedure is mandatory. The fracture will not be opened during surgery. The type and length of the plate, method of reduction, need for special instruments to achieve it, the plate insertion site, technique, and position, as well as the order of any screws, has to be determined from scaled x-rays preoperatively.

Most cases are performed with the patient supine on a radiolucent table to enable fracture manipulation under image intensifier control and accurate intraoperative assessment of limb alignment. It is tempting to use a fracture table to maintain the length and the rotation of the limb but this can make intraoperative assessment of the limb alignment difficult.

Two separate incisions are made over the intact bone each side of the fracture, preferably outside the zone of injury. The soft tissues are dissected down to the periosteum, which is left intact. The plate is then inserted subcutaneously or submuscularly over the periosteum, either after preparing a tunnel with a tunneling instrument or by using the plate itself (Fig 2.11-1).
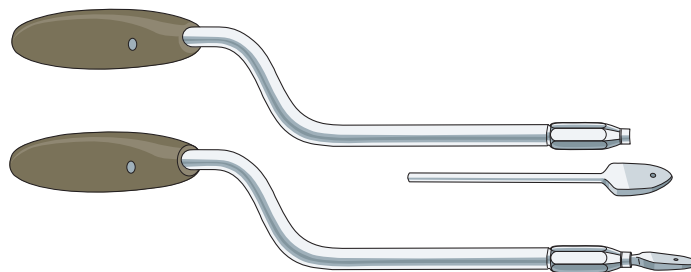
Fig 2.11-1   Tunneling instrument.

Author   Theerachai Apivatthakakul

Reduction techniques

Fracture reduction is usually the most difficult step in MIPO and must form part of the preoperative plan. The surgeon and operating room personnel should be familiar with the different reduction techniques and instruments and how to use them.

Special instrumentation

New instruments for closed fracture reduction are still evolving, but those introduced so far can be broadly grouped into those which aid fracture reduction and/or maintain reduction, and those which aid plate insertion and fixation.

Instruments to aid fracture reduction and/or maintain reduction

- Joysticks or Schanz screws on T-handles: inserted into the bone, they are used as manipulators of bone fragments to reduce fractures or to control the position of the bone fragments (Fig 2.11-2).
- Large distractor: applied with a Schanz screw to each end of a long bone, the large distractor is used to maintain the reduction by distraction, using the soft-tissue envelope to realign the fragments of a multifragmentary fracture (Fig 2.11-2).
- Reduction handles or manipulators: the manipulators combine thick self-drilling threaded guide wires drilled into the bone with a reduction handle which is placed over the guide wire and grips the bone as a wing nut, screwed on top of the guide wire, is tightened. After manipulation of the fracture fragments, the tops of the guide wires can be connected with clamps and rods (like an external fixator) to maintain the reduction (Fig 2.11-3).
- External fixator: the Schanz screws, clamps, and bars of a modular external fixator can be used as reduction handles for indirect fracture reduction and are then fixed together across the fracture site to maintain the reduction. An external fixator can also be used as a distractor (Fig 2.11-3).

- Collinear reduction clamps: these are reduction forceps with offset modular arms of three different sizes (to avoid the soft tissues), which can be inserted through small stab incisions each side of a fracture for direct fracture reduction (Fig 2.11-4). One arm is cannulated to allow insertion of a guide wire or temporary K-wire.
- Cerclage passer: this device facilitates the passing of a wire through a small incision and around a long oblique or spiral fracture to hold the reduction. The system has a cerclage tunneling device and a dividable forceps which permit the guide to be inserted in separate halves so as to minimize the incision size (Fig 2.11-5).
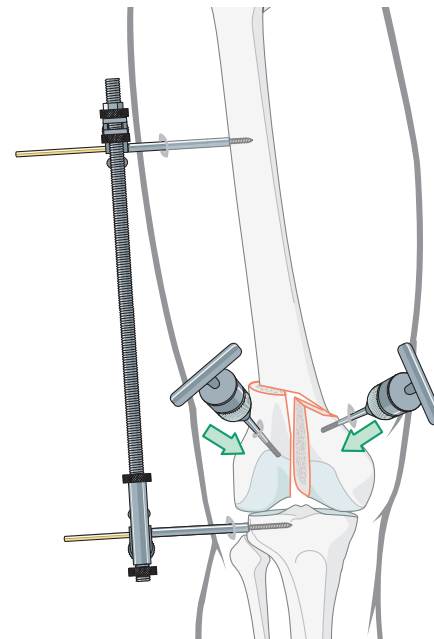
Fig 2.11-2   Use of two Schanz screws as joysticks to reduce a distal femoral fracture.

a

b
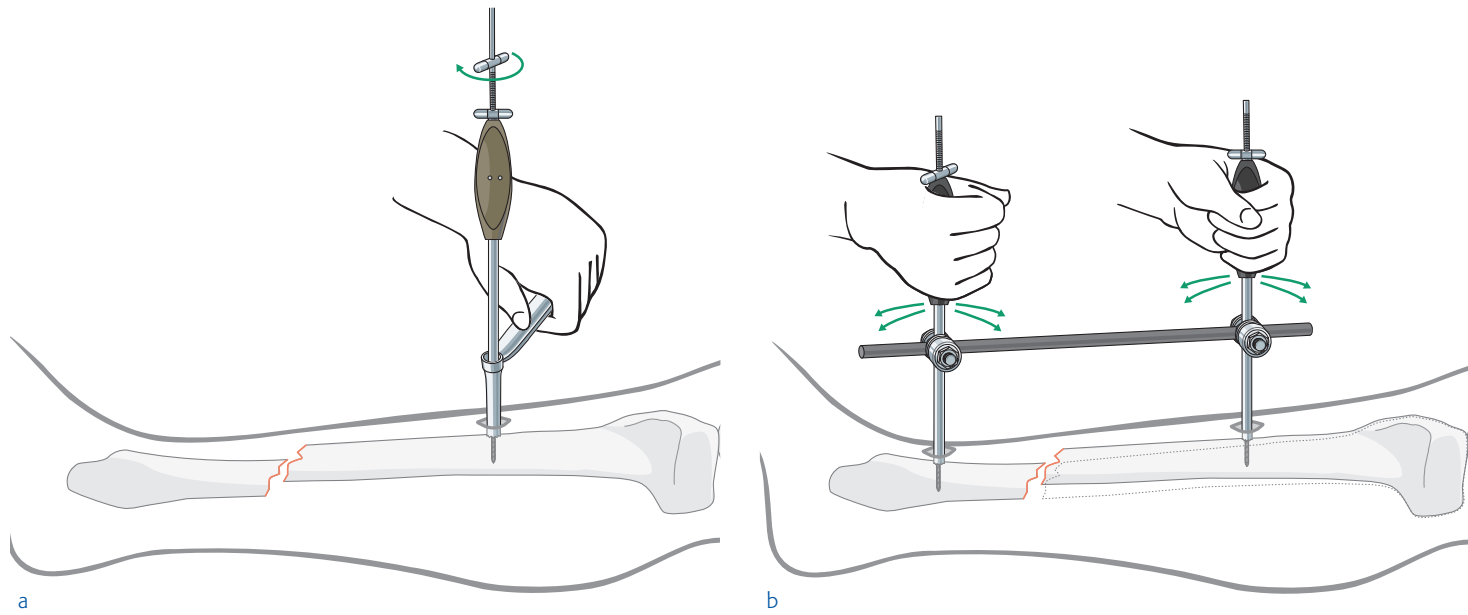
Fig 2.11-3a–b   Reduction handles used as manipulators, which may be combined with an external fixator.
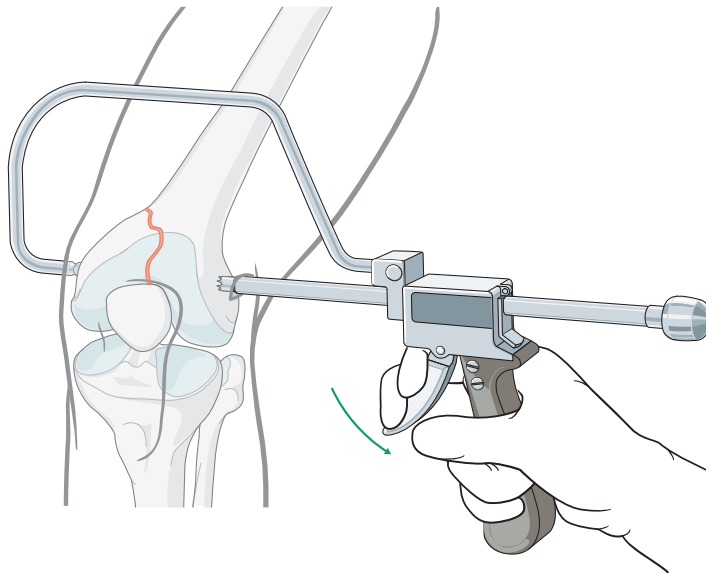
Fig 2.11-4   The collinear reduction clamp.

Author   Theerachai Apivatthakakul

Instruments to aid plate insertion and fixation

- Soft-tissue retractor or tunneler: this instrument is used to prepare a pathway for introduction of the plate in a submuscular extraperiosteal plane. Its length can be adjusted by extending the blade (see Fig 2.11-1). The small hole at the tip of the blade allows a suture to be attached, which can then be tied to the end of the plate so it can be pulled back up the tunnel.
- Plate holder: the plate selected can itself be used to create the submuscular tunnel by attaching a plate holder to the threads of a locking hole at one or both ends of the plate, thus using it to manipulate the plate (Fig 2.11-6).
- Hohmann holder: this instrument is used to hold a pair of Hohmann retractors apart to retract the soft tissues of a small incision without the need of an assistant (Fig 2.11-7).

a

b

Fig 2.11-5a–b   The wire passer placed around the bone in two halves and then assembled.
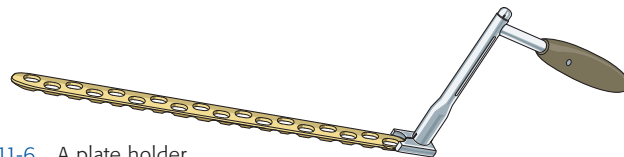
Fig 2.11-6   A plate holder.
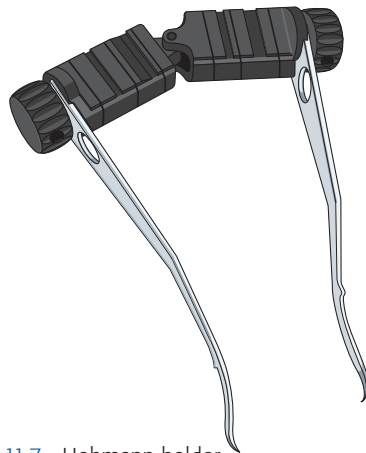
Fig 2.11-7   Hohmann holder.

Fixation techniques

In conventional plating, definitive fixation usually follows the reduction of the fragments and the temporary maintainance of reduction with instruments. This strategy should also be followed in MIPO fixation. While it is possible to fix the plate to one fragment first and then reduce the fracture onto the plate before fixing the other end, in practice this is technically difficult and likely to lead to malreduction, particularly in the hands of inexperienced surgeons.

Intraoperative assessment of limb alignment

Since the fracture is not directly visualized, it is vital that following fixation the limb alignment is assessed clinically and checked using with the image intensifier. This is one of the most important steps in any fracture managed with indirect reduction and a minimally invasive technique.

Postoperative treatment

Postoperatively, patients with articular fractures must be encouraged to mobilize the affected joint (sometimes with the help of continuous passive motion), while weight bearing may initially have to be avoided or restricted. Fractures which do not involve the joint can normally be mobilized more aggressively with partial or full weight bearing from the outset, although the exact regimen will depend on the fracture, the method of fixation, the patient's compliance, and the bone quality.

Complications

The main aims of the MIPO technique are the preservation of blood supply to the fracture site and minimizing soft-tissue injury to avoid the complications that occur in conventional plating, particularly infection and wound breakdown leading to delayed or nonunion and subsequent implant failure.

Most complications which occur in the MIPO technique are due to failure of the surgeon to obtain adequate fracture reduction and temporary stabilization before definitive fixation, leading to limb length discrepancy, malalignment, or malrotation. These complications are much better tolerated in the upper limb than the weight-bearing lower limb.

Well-performed MIPO has a lower rate of delayed union and nonunion leading to less need for further surgery than conventional plating. When complications occur, they are frequently due to preventable technical errors caused by poor preoperative planning or inadequate experience, equipment, or expertise.

2.11.4   Conclusion

MIO is not a new concept in fracture treatment, but the introduction of locking plates has widened the indications for its use. The advantages of smaller incisions leading to less soft-tissue trauma and less postoperative pain for the patient as well as earlier mobilization, a shorter hospital stay, and better outcomes can only be achieved if the surgery is carefully planned and performed well. It is much better to perform open surgery well than MIPO badly.

Because of the perceived benefit it provides to the soft tissues, and therefore fracture healing, the indications for MIO will continue to expand. However, the difficulty in achieving accurate axial alignment and rotation in long-bone fractures, and the surgeon's high exposure to radiation remain unsolved problems. Additional improvements in instrumentation and implants, together with better imaging and intraoperative navigation will gradually produce solutions to these difficulties, further increasing the indications for MIO and establishing its position as one of the mainstays of fracture management in years to come.

Author   Theerachai Apivatthakakul

2.11.5   Further reading

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2.12   Bone grafting

Author   Mamoun Kremli

2.12   Bone grafting

2.12.1   Introduction

Bone grafting refers to a wide variety of surgical methods for augmenting or stimulating the formation of new bone wherever this is required, and is a common procedure in orthopaedic surgery. After blood, bone is the second most commonly transplanted tissue with more than 2 million bone graft procedures performed worldwide every year.

This chapter describes the indications for using bone graft and bone graft substitutes, and the materials available together with an outline of how they help the formation of new bone. Some of the surgical techniques used for harvesting bone allograft are presented.

2.12.2   Indications

There are five broad clinical indications for bone grafting:

- Fresh fractures: In fresh fractures bone grafts and bone graft substitutes are used for two main reasons. They may be used to provide mechanical support or be used to speed up healing. Mechanical support is frequently required in the fixation of depressed articular fractures of the proximal and distal tibia and the distal radius. Speeding up of the healing process is required when the fracture treated is likely to take a long time to heal and it is possible that the implant will fail before fracture healing has occurred. Classically this is seen in plating of shaft fracture using absolute stability techniques when it is not possible to restore the bone surface opposite the plate.
- Delayed union and nonunion of fractures: Bone grafting is one of the principal ways of managing fractures that have failed to heal after initial treatment. It is particularly important when the reason for delay in healing is because of poor biological environment at the fracture site caused by inadequate blood supply or bone defects.

- To regenerate lost or missing bone: Bone grafting may be used when there is bone defect because of trauma, when a segment of diseased bone has been excised (eg, osteomyelitis), or when excision or curettage of a bone cyst has left a defect.
- To help the process of arthrodesis (fusing) of a diseased joint: This is particularly common in spinal fusion. The addition of bone graft can also assist in the fusion of other damaged joints, including the ankle or wrist.
- To improve the bone stock around a prosthesis: This is usually only required in revision procedures for total hip or total knee replacements.

2.12.3   Methods of bone stimulation

Bone grafting enhances the formation of new bone by three naturally occurring methods of bone stimulation:

Osteogenic stimulation

This is the ability to stimulate local bone-forming cells, osteoblasts, to produce new bone. Osteoblasts are present in fresh bone autograft taken from the same patient. Osteoblasts can also form from primitive stem cells, in bone marrow aspirated from a patient, when subjected to an osteoinductive stimulus (see below). Bone marrow can be injected into an autograft or allograft site or mixed with bone substitutes before being used in that patient.

Osteoconductive stimulation

Osteoconduction is the ability of material to serve as a scaffold on which bone cells can attach, migrate, and divide. Osteoconductive materials improve the ability of bone cells to fill the gap between two-bone ends. They also serve as a spacer that reduces the ability of fibrous tissue around the graft site from growing into the site. Bone grafts are the best osteoconductive material. Other naturally occurring and synthetic osteoconductive materials are also available.

Osteoinductive stimulation

Osteoinduction is the ability to stimulate primitive nondifferentiated bone cells to grow and mature into bone-forming osteoblasts. A number of growth factors present in normal human bone have been demonstrated to be osteoinductive. These are proteins which were first discovered in 1965 by Marshall Urist who coined the term "bone morphogenetic protein" (BMP). Subsequent studies have identified many different BMPs as well as other naturally occurring factors that stimulate bone growth.

2.12.4   Types of bone grafts

There are three types of bone graft, ie, autograft, allograft, and xenograft, depending from whom the graft has been taken. Each has advantages and disadvantages.

Autografts

Autografts are bone taken from and inserted into the same individual. They are osteoconductive, osteoinductive, and osteogenic and have become the standard by which all other biological methods of bone stimulation are measured. Autograft is usually harvested as fragments of cancellous or corticocancellous bone from the anterior or posterior iliac crest. Smaller amounts can be obtained from the proximal tibia, the greater trochanter, the distal radius, and the olecranon. In spinal surgery, spinous processes and ribs can be used. As dry air kills cells, autografts are best harvested shortly before they are required for use. The graft may be temporarily covered and stored with saline or blood-soaked gauze for up to 2 hours.

Occasionally a large segment of bone with its nutrient blood vessels and with or without its soft-tissue attachments can be transferred as a free-vascularized autograft to fill a large-bone defect. The vessels are reanastomosed to local vessels to provide the graft with a blood supply. This procedure is demanding and is usually performed by plastic surgeons.

Cortical and strut bones, usually the fibula, may be used when a graft requires additional strength for load bearing. Cancellous bone incorporates faster than cortical bone but cannot be expected to take much load. Corticocancellous block grafts are useful when there is a need to provide a structural support that heals quickly, usually filling defects in and around joints, particularly when there are missing pieces of bone or joint surface. Most of the time it is harvested by cutting out a suitably shaped section of the anterior iliac crest.

The advantages of autografts include their availability in all patients, the fact that there is no risk of disease transmission or graft rejection, and that it requires no special processing technique. Disadvantages include the variability of graft quality (particularly poor in osteoporotic patients), and the limited quantity of the donor-site bone. Harvesting autograft tends to increase operating time and graft donor sites have complications of varying severity occurring in about 10–35% of patients.

Allografts

Allografts are bones taken from another human being. They are only osteoconductive as they contain no living osteoblasts and are not as effective as autograft in promoting healing. Allograft cancellous bone is harvested from living donors, during total hip and occasionally total knee replacement surgery, while cortical bone in the form of strut grafts and even whole bones are from cadaver organ donors. The bone is usually stored frozen at minus 70°C in tissue banks, or freeze-dried and stored at room temperature. Both methods destroy the osteoinductive and osteogenic properties of the bone, and freeze-drying also decreases its mechanical integrity.

Allograft has the advantage of ready availability in the quantity and configuration required and eliminates donor-site complications. Because allograft is only osteoconductive it is not as effective as autograft. Disease transmission (bacterial and viral) has been reported and remains a major concern, despite various treatments

Author   Mamoun Kremli

to try and render allografts pathogen free. Allograft should therefore be quarantined until living donors have been tested for HIV and other viral diseases at least 90–180 days after surgery.

Xenografts

Xenograft is bone from another species, ie, animals. Deprotinized bone from calves, known as Kiel bone was introduced in 1957. These are only osteoconductive. They are less effective and structurally weaker than allografts and are far inferior to autografts. The use of xenografts has largely been replaced by allografts and other bone substitutes.

2.12.5   Bone-graft substitutes

Using bone substitutes eliminates both the supply and infection problems associated with both autografts and allografts. However, most bone substitutes that are currently available are brittle and unable to withstand significant load bearing. Extensive research is being conducted to improve this situation.

Osteoconductive substitutes

These are naturally occurring or synthetic substances that have similar biomechanical properties and structure to that of bone. They include calcium triphosphate, hydroxyapatite, calcium carbonate, and glass-based cements. They are not biologically active and are only providing a scaffold of a porous structure similar to bone on, and along, which cells can creep and multiply. They are sometimes used alone in small defects but tend to be combined with autograft or allograft in larger ones.

Osteoinductive substitutes

These are substances containing BMPs. Naturally occurring BMPs are found within bone in small amounts. Clinically useful and reproducible amounts of isolated human BMPs are manufactured by a genetic-engineering process called recombination. These are either used with a carrier (eg, a collagen sponge) or added to osteoconductive materials. Recombinant human BMP-2 has been studied more than any other BMP. It has been proven to be equally successful when used combined with autograft in spinal fusion and nonunion, as when used combined with a collagen sponge in open tibial fractures.

Demineralized bone matrix (DBM) is demineralized allograft bone that retains proteins, therefore some of its osteoinductive properties. It is supplied as flexible strips, a gel, malleable putty, a moldable paste with bone chips or injectable bone paste, and is easy to handle. It is best used to augment rather than replace autograft.

Neither the synthetic BMPs nor DBM have any structural integrity unless mixed with bone graft or an osteoconductive substitute, and both have the disadvantage of being expensive.

2.12.6   General considerations

Whatever the type of graft used, proper surgical technique and tissue handling are essential in the success of grafting. Bone graft fragments should be well impacted into the site where they are required to promote healing. Loose fragments tend to be absorbed and are not useful. Stability of the graft and a healthy tissue bed with good blood supply are crucial. The presence of uncontrolled infection is a contraindication to bone grafting, as the graft rapidly becomes infected and requires subsequent removal if it is not reabsorbed. It is therefore generally best to delay grafting in open fractures until the wound has healed and the major risk of infection has passed.

To improve the success rate of autogenous bone grafts and graft substitutes, surgeons can mix osteoinductive materials with osteoconductive ones. For example, fresh bone marrow aspirate, BMP, or DBM can be added to allograft or synthetic osteoconductive materials.

2.12.7 Harvesting bone graft

Bone autograft is almost always harvested from a patient during the procedure in which it is to be used.

Most autografts are taken from the anterior iliac crest of the pelvis. Even more bone can generally be harvested from the posterior iliac crest but this requires the patient to be lying in a lateral or prone position, which makes it unsuitable for most procedures except for those on the spine.

Other sources of limited amounts for cancellous allograft include the greater trochanter of the femur and the metaphyses of the distal radius, proximal ulna, and proximal tibia, all of which are relatively accessible (Fig 2.12-1). Removal of too much cancellous bone from the greater trochanter weakens it to the point when a femoral neck stress fracture can occur.

To take small amounts of cancellous graft from a metaphyseal region, the bone surface is exposed and a window made in the thin cortical bone with an osteotome, being careful to leave a soft-tissue attachment and hinge on the elevated segment. With the cortical bone elevated, the accessible underlying cancellous bone can be scooped out using a curette. Once the cancellous bone is harvested, it is important to replace the cortical window and if possible suture it back into place.

Graft may be harvested from the iliac crests in various ways. The method used depends on the surgeon and the type of graft required.

The wing of the ileum is made up of two plates of cortical bone, with a layer of cancellous bone between them. Cancellous bone can be harvested either by removing the top of the iliac crest with an osteotome and scooping out the bone with a curette (Fig 2.12-2)

a   b   c   d   e   f
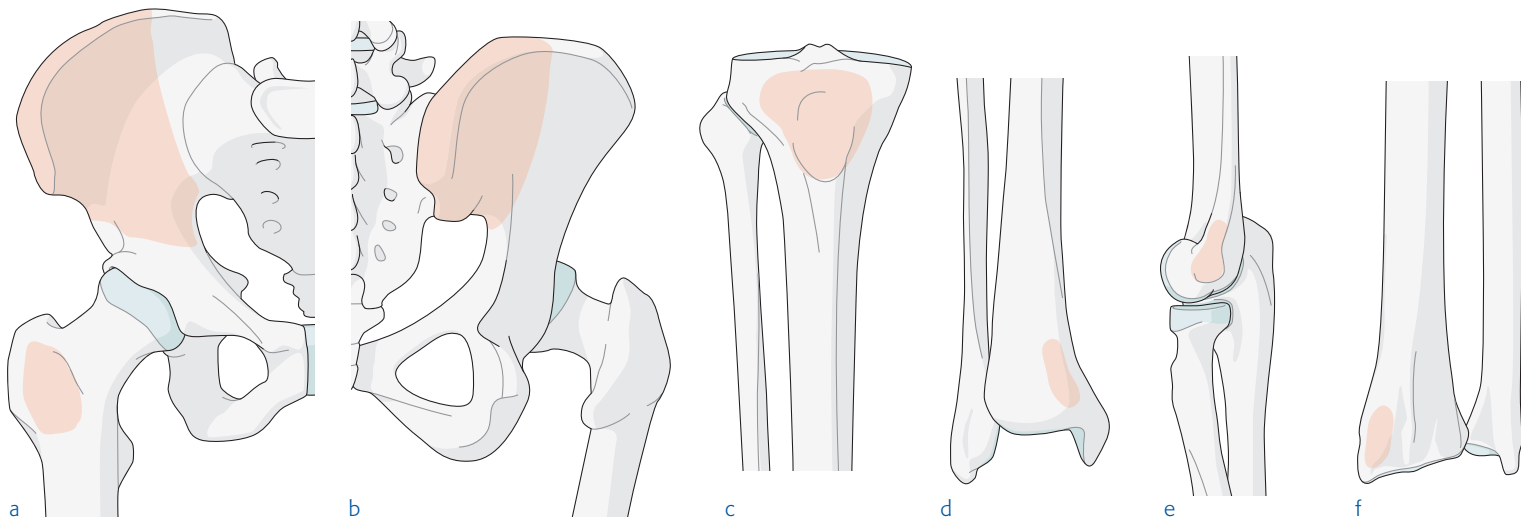
Fig 2.12-1a–f   Sources of cancellous bone graft.
a   Anterior iliac crest and greater trochanter.
b   Posterior iliac crest.
c   Proximal tibia.
d   Distal tibia.
e   Distal femur.
f   Distal radius.

Author   Mamoun Kremli

before reattaching the crest with sutures, or by making a window in the wing. This second method tends to be less painful postoperatively. Corticocancellous strips of bone can be taken from the inner or outer wing of the ileum with an osteotome or gouge (Fig 2.12-3).

When structural graft is required a bicortical block can be cut from both surfaces of the iliac wing, leaving the iliac crest intact (Fig 2.12-4). Provided the muscles are reattached, this will usually provide a good functional and cosmetic result. If a tricortical graft is required, it has to be cut from the wing and crest of the ileum. Depending on the size of the segment removed this may create a poor cosmetic appearance, and it has a significant risk of postoperative morbidity.
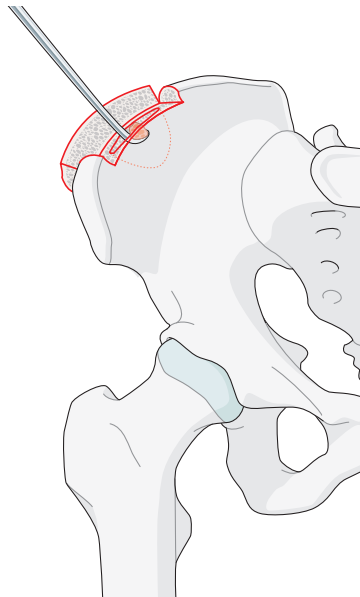
Fig 2.12-2   Harvesting of cancellous bone graft from the iliac wing with a curette.
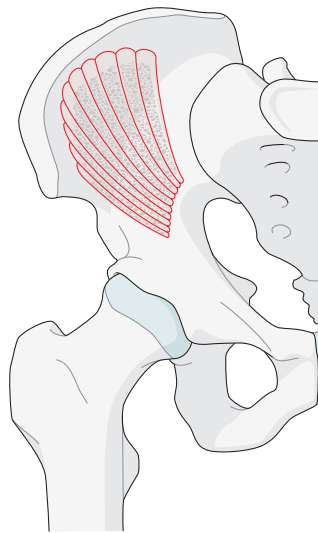
Fig 2.12-3   Harvesting of corticocancellous bone strips from the iliac wing.
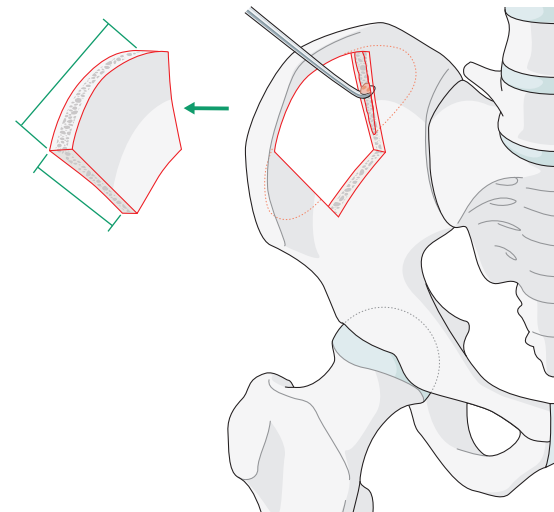
Fig 2.12-4   Excision of a bicortical bone block from the iliac wing. Additional cancellous bone can also be harvested.

2.12.8 Future of bone grafting

Advances in understanding of basic bone biology, gene therapy, and tissue engineering have recently allowed users to combine the two basic criteria of a successful graft, ie, osteoconduction and osteoinduction, in the production of synthetic alternatives to autograft bone. Further advances will hopefully produce more effective graft substitutes which have an osteoconductive base with potent osteoinductive power and biologically active cells that have a potential for bone formation.

2.12.9 Conclusion

Bone grafting is widely used in both acute trauma surgery and in the management of nonunion. Autograft can be harvested from an individual and is the best form of graft available. Alternatively, frozen or freeze-dried allograft or a structural bone graft substitute will have osteoconductive properties and can be used alone or in conjunction with each other. The addition of BMP, bone marrow, or DBM will provide osteoinduction. None of these are appropriate for use in the presence of an uncontrolled infection.

2.12.10 Further reading

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2.13   Complications

Author   Benjamin Ollivere

2.13   Complications

2.13.1   Early complications

Complications may occur following the management of any fracture. They can be caused by the injury, immobility, infection, or be iatrogenic. Few complications are completely avoidable, but their frequency may be reduced by recognizing and reducing any predisposing risk factors. Early diagnosis and prompt treatment of complications reduces their impact on the patient.

Certain patient factors may increase the risk of complications. Common diseases, such as diabetes, peripheral vascular disease, neurological conditions, and osteoporosis profoundly increase the risks of complications occurring during treatment. Drugs, including immunosuppressives, nonsteroidal antiinflammatories, and some antibiotics, such as ciprofloxacilin may impair bone healing.

Injury

The "personality" of the fracture (see chapter 2.1) plays both an important role in decision making in the preoperative period and in determining the likelihood of complications. In patients with severe multiple injuries, the high energy transferred to the soft tissues causes swelling and inflammation. This not only places them at risk of developing multiple organ failure which can accompany the systemic inflammatory response syndrome (see chapter 2.9), but also increases the frequency of other local and systemic complications, including compartment syndrome, pulmonary embolus, and infection. The frequency of these local complications also tends to increase with the severity of any isolated injury.

Immobility

Patients who have a prolonged postoperative recovery and re- duced mobility are at risk of complications, particularly medical ones, associated with their immobility. These include pneumonia, deep vein thrombosis (DVT), and pressure sores; while in the lon- ger term immobility leads to osteoporosis. These complications rarely require further surgical intervention, and their frequency and severity is reduced by a management strategy which encourages early mobilization and aggressive postoperative rehabilitation. In practice this means early osteosynthesis of any fractures that delay patient mobilization.

Infection

Early acute infection usually occurs in patients who have had a combination of soft-tissue damage and contamination. This may occur at the time of injury or of surgery, or a combination of both. Infection is therefore more likely in patients presenting with high- energy injuries, poor soft tissues, and with open and contaminated wounds. The resulting soft-tissue edema, reduction in blood supply, and loss of an effective epithelial barrier allows for bacterial colonization and wound infection. Systemic factors also play a major role in the frequency of infection. Patients taking steroids, smokers, diabetics, and those who are immunosuppressed have significantly higher rates of postoperative infection.

Operative factors can further increase the risk of infection. Contamination of the wound, the operative field or instruments, rough handling of soft tissues, and excessive surgical time have all been implicated in increasing the rate of postoperative infection.

Blood supply to the affected area is also of profound importance in both tissue healing and infection. Injuries in areas with poor vascular supply, such as the foot and ankle, are more prone to infection. Excessive stripping of soft tissue from fractured bone, depriving it of its blood supply, will make the problem worse. Patients with vascular disease are also much more likely to develop infection and healing problems. Although often stated, there is no evidence that use of self-retaining retractors in limb surgery increases risk of infection. However, like all instruments they must be properly used and not applied to the tissue with excessive tension.

Effective treatment of early deep infection revolves around four principles:

- Maintenance of stability: A fracture can heal in the presence of infection provided the fracture remains stable. Well fixed metalwork can therefore be retained in the presence of infection. Instability may occur in early deep infection due to failure of fixation. In such cases the fixation needs to be revised or replaced with an alternative fixation method—usually an external fixator. Loose metalwork must be removed.
- Debridement and lavage: Any infected collections must be washed out and any necrotic tissue must be excised.
- Skin coverage and revascularization: Infection may present with a sinus or ulcer, often with exposed metalwork at the base. Poor blood supply to the soft tissues and skin loss may be addressed through various plastic surgical flap techniques. Improving the blood supply and soft-tissue envelope will help combat infection.
- Antibiotics: Appropriate use of antibiotics is essential in the infected wound. Antibiotics should not be started until a culture swab, and preferably also a tissue sample, has been obtained. Samples taken from the skin around a sinus may fail to grow the causative organism of the deep infection. This allows for therapy to be tailored to the organisms' antibacterial sensitivities.

Decision making in the treatment of early acute infection can be difficult. For patients in whom fracture healing has begun it may be appropriate to debride the wound and suppress their infection with antibiotics until healing has occurred. For those with no evidence of healing or in whom stability is compromised, removal of the loose metalwork and more radical surgery can be considered. Use of intramedullary nails to increase fixation in bone which is already infected carries with it the risk of spreading the infection throughout the medullary cavity of the bone, and should be avoided.

Iatrogenic

Injury at the time of surgery (or iatrogenic injury) is not always completely preventable.

Care in the handling of soft tissues is vital. Rough handling can cause the fractured bone to lose its soft-tissue attachment and with it its blood supply. This will always compromise fracture healing.

Nerve injury is divided into three types of lesion:

- Neuropraxia: consists of bruising and loss of function in an intact nerve
- Neurotemesis: the whole nerve is divided in two
- Axonotemesis: neurones in the nerve sheath are divided but the sheath itself remains intact, so that the nerve looks intact on casual assessment

Patients with neuropraxia and axonotemesis will usually recover spontaneously, although this may take months or occasionally years and recovery may be incomplete, while neurotemesis requires surgical exploration and repair.

Iatrogenic nerve injury is mostly associated with specific surgical approaches, for example, to the radial nerve in diaphyseal humeral fractures. When a complete nerve lesion develops postoperatively, it is usually advised to reexplore the operative site to check the integrity of the nerve and repair it if it has been damaged. When an incomplete lesion is seen, conservative treatment is usually correct as most patients with such lesions will recover given enough time.

Author   Benjamin Ollivere

2.13.2   Late complications

Late complications in trauma are nearly always associated with delayed bone healing. They include chronic infection, delayed union, and nonunion all of which may be linked with a failure of fracture fixation.

Failure of fixation occurs through repeated cycles of loading and resultant fatigue of the implant. This may happen through loss of fixation in the form of back-out or cut-out of the securing screws, or a fatigue fracture of the metal plate, screw, or nail. All metalwork will eventually fail, but in most cases the bone heals before failure occurs. However, if the fracture is poorly reduced or wrongly fixed, when there is a delay in bone healing, or when chronic infection results in bone reabsorbing around the screws which then loosen, the fixation is likely to fail before the bone heals.

Chronic infection (and infected nonunion)

Chronic infection in trauma surgery invariably results in osteomyelitis and nonunion. Infection may develop from contamination at the time of injury or surgery, or may follow a poorly treated acute infection. The formation of pus around the fracture may devitalize fracture fragments. These dead fragments of bone become sequestrated and, colonized by bacteria, contributing to the persistence of infection. As the infection progresses, granulation tissue around the infected area will transform into a dense layer of fibrous tissue and periosteum. This isolates the infected area from the surrounding normal tissue and makes treatment difficult. Because the area becomes isolated from the body's own defence mechanism as well as from circulating antibiotics used to treat the patient.

Antibiotic treatment has little effect on chronically infected bone. Surgical debridement is the most effective form of treatment. Surgical treatments require debridement with excision of all dead and infected bone and soft tissue, followed by establishing fracture stability, usually with an external fixator. For small areas of infection, decortication of affected bone and subsequent bone grafting may be sufficient. For more severely affected bone, complete excision of the infected segment may be required with subsequent bone transport using a circular (Ilizarov) frame external fixator.

The management of chronically infected bone is a complex issue and such cases are normally best managed in specialist centers.

2.13.3   Nonunion (aseptic)

Delayed union is when a bone fails to unite within the expected period, but still has the potential to heal; whereas nonunion is when the healing process has stopped but the fracture site still exists. The cause of failure to heal is either mechanical, with instability or failure of fixation at the fracture site, or biological, usually caused by disruption to the vascular supply to the fracture or soft tissue, or a combination of the two.

To achieve successful treatment of an established nonunion it is vital to address the cause of the problem. It is not sufficient to simply perform 'refixation.' Nonunion most commonly presents as either atrophic (no bone formation) or hypertrophic (bone formation but no healing). Atrophic nonunions usually represent a biological or healing problem, whereas hypertrophic nonunions are due to excessive movement at the fracture site.

The primary goal in surgical intervention for hypertropic nonunion is to address the mechanical environment (Fig 2.13-1). Although it may be necessary to replace fatigued or fractured metalwork, the mechanical environment may equally be altered by adjustment of fixation. Dynamization of a nail can provide compression to a fracture fixed with an intramedullary nail, while stability of a plate may be altered by addition or removal of screws.
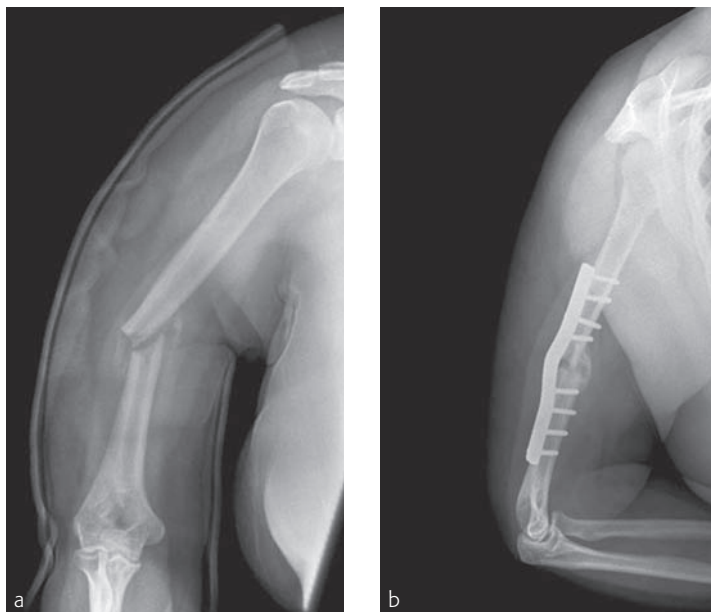
Fig 2.13-1a–b
a   Nonunion of a humeral fracture because of excessive movement.
b   Stabilization of the fracture with a contoured plate.

Treating atrophic nonunion requires improvement in the biological environment. Modification of risk factors for atrophic nonunion is essential before undergoing surgery. These include stopping smoking, nonsteroidal antiinflammatory drug and steroid use wherever possible, while optimizing diabetic control, and improving poor nutritional status. Successful surgery for atrophic nonunion relies on optimizing both the fixation and the biology. Techniques include exploration of the fracture site, stable fixation possibly with scar and fibrous tissue excision, and biological augmentation with bone graft or bone morphogenic protein as required (see chapter 2.12). In surgery for atrophic nonunion without segmental bone loss the aim is usually to achieve absolute stability at the fracture site.

2.13.4   Malunion

Malunion is the healing of a bone in such a position as to impair function. Malunion usually occurs when length, alignment, or rotation is not restored after an injury. The site of the malunion is as important in determining the effect on function as the deformity itself.

Limb length discrepancies are well tolerated in the upper limb but not in the leg. Surgical interventions have no absolute indications and most procedures have mixed results. Osteotomy and plating may be contemplated for discrepancies of up to 5 cm, while larger discrepancies can be addressed gradually through distraction osteogenesis with an Ilizarov frame or monoaxial fixator.

Intraarticular malunion is an incongruity in two articulating surfaces. It occurs when there is more than 2 mm step in the joint line. However, disruption to the articular cartilage usually exceeds the radiographically visible bony deformity. Treatment options depend on the age and functional demands of the patient. In the older patient arthroplasty is an attractive option, allowing preservation of motion; whereas in the younger, higher-demand patient the shortened-life expectancy of an arthroplasty may make arthrodesis a more attractive treatment option, particularly in the ankle joint.

Metaphyseal malunion results in the joint surface becoming malaligned. The most common presentation is deformity with or without pain. In cases when there is pain or function is impaired, corrective osteotomy and reorientation of the articulating surface may improve matters. It may sometimes be appropriate to perform a corrective osteotomy even before the patient develops symptoms to improve the long-term prognosis by reducing the risk of posttraumatic osteoarthritis. Treatment decisions should be made on an individual basis.

Author Benjamin Ollivere

Diaphyseal malunion, surgery should be contemplated when the deformity alters the biomechanical axis of the limb or in cases when rotational malalignment causes functional impairment. Diaphyseal malunion may be corrected at the fracture site, or through a compensatory metaphyseal osteotomy.

Successful treatment of symptomatic malunion is dependent on meticulous preoperative planning to ensure adequate and successful correction of the preexisting deformity.

2.13.5   Conclusion

The potential complications of fractures and fracture surgery can be devastating to the patient, and if recognized at a late stage can lead to serious permanent disability or even death. The whole team should always be on the alert for possible complications, and be prepared to intervene early to minimize the consequences for the patient.

2.13.6   Further reading

Bucholz RW, Heckman JD, Court-Brown C, eds (2005)
Rockwood and Green's Fractures in Adults. 6th ed. Philadelphia New York London Sydney Hong Kong: Lippincott Williams&Wilkins, 563.
Phieffer LS, Goulet JA (2006) Delayed unions of the tibia.
J Bone Joint Surg Am; 88:205–216.
Zalavras CG, Marcus RE, Levin LS, et al (2007) Management of open fracture and subsequent complications. *J Bone Joint Surg Am;* 89:884–895.

2.14 Implant removal

2.14   Implant removal

2.14.1   Introduction

Implant removal is unfashionable, neglected, occasionally disparaged, often delegated to junior surgeons, but full of surprises and traps for the unwary.

2.14.2   Indications for implant removal

We should start from the position that there is no such thing as "routine" removal of an implant. Asymptomatic metalwork is generally best left in situ because all surgical procedures are risky. There must therefore be a reason to advise a patient to accept these risks. These reasons include:

Prominence: Prominent implant, particularly those adjacent to joints such as the LISS plates and plates on the lateral malleolus of an ankle, may impinge on the soft tissues, cause pain, and inhibit movement.

Loosening and failure: An implant that is loose or has broken generally means that the race between biological success (fracture healing) and mechanical failure of the implant has been lost. Fig 2.14-1 illustrates such a case. The implant must be removed before further treatment is possible.

Infection: Most pathogenic organisms have the ability to adhere to the surface of implants and to protect themselves with a muco-polysaccharide envelope or shelter where they cannot be reached by the body's defences or antibiotics. Organisms in this "colonic" form remain a constant threat for recurrent infection. To eliminate this risk, it is usually necessary for the implant to be removed.

Pain: Pain may be due to prominence, impingement, or occasionally a biological reaction to the implant. Stainless steel implants are more likely to cause such a reaction than titanium implants. It may be difficult to establish the precise reason for pain in the vicinity of an implant and it may be that it is only the resolution of the pain when the implant has been removed that confirms that it was the implant causing pain.

Proximity to growth plate: Metaphyseal implants in children are generally removed because of fears that they may impede or distort bone growth.

To facilitate other procedures: Implanted metal may interfere with or prevent subsequent surgery. For example, a sliding-hip screw in the proximal femur would prevent hip replacement unless it was removed, and a corrective osteotomy for malalignment may be complicated by a previously implanted fixation device. In some fracture nonunions (Fig 2.14-2), the original implant must be removed before the nonunited fracture can be stabilized.

Fig 2.14-1   Fracture fixation has failed.

Fig 2.14-2   Nonunion of the humerus, the nail must be removed and the fracture stabilized.

Biological effects of the products of corrosion: All metals corrode, and the products of corrosion are generally biologically active. Some metals corrode more than others. Stainless steel, particularly if of poor quality, corrodes much more than materials such as titanium. Corrosion may be "fretting" or "galvanic." Fretting corrosion occurs when two metal fragments rub together and release small particles. Galvanic corrosion occurs when an electrical current is established between two components of the metal implant. This is particularly important if different metals are used within the same implant.

Corrosion results in the release of metal ions into solution. These products of corrosion are biologically active. They may cause an allergic reaction and there is concern that prolonged exposure to some metal ions may be oncogenic, although this has not yet been clearly established. This is an important area of research but has no immediate implications for the enormous benefits of using these materials in fracture fixation, although it may be a reason to consider implant removal in younger people.

2.14.3 Risks of implant removal

The general risks of all surgery, including risks of anesthetic, are inevitable. These include infection, wound breakdown, poor scarring, and deep vein thrombosis (DVT).

The specific risks to implant removal are:
Failure to remove implants: this is a disastrous outcome which occasionally reflects a challenging technical difficulty but more often stems from poor planning and inadequate provision of equipment. Broken implants, mainly locking bolts of intramedullary nails, stripped screw heads, cold-welded implants (particularly sliding hip screws manufactured from steel of different quality), and cross-threaded locking screw heads all pose unusual difficulties. These must be anticipated.

Refracture: defects in the bone from removed implants, mostly screws, weaken the bone by 30% or more. Refracture has been reported to occur in 1–3% of patients following implant removal. Patients must be advised to avoid load bearing or impact for up to 12 weeks following implant removal depending on the circumstances. Equally, premature removal may lead to early refracture. Figures given below for timing of fracture removal are only guides. The fracture must first heal.
- Metaphyseal fractures: 3–6 months
- Diaphyseal plates: 12–18 months
- Intramedullary nails: 8–24 months

Nerve injury: removal of forearm plates, mainly from the radius, has been linked to a high level of nerve injury.

2.14.4 Techniques of implant removal

Planning is as important in implant removal as in fracture fixation. It requires:

Recent x-ray: Implants may be buried in new bone, broken, or may have moved, especially K-wires. Updated x-rays are crucial.

Implant identification: Populations and patients are increasingly more mobile. It is possible that the implant to be removed was put in at another hospital or even in another country. Many implants look similar but require different equipment for removal. It may be necessary to contact the original hospital for details.

Obtain the correct equipment: Generic equipment for removal of intramedullary nails has been available for some years. However, there are difficulties in using this equipment. For legal reasons relating to copyright and patent, generic equipment cannot be linked specifically with implants of other manufacturers. This restriction makes generic nail extraction sets surprisingly difficult

Author   Graeme Groom

to use. There is no substitute for obtaining the correct equipment for implant removal from the manufacturer.

Surgical tactic: This is no different from an operation for fracture fixation. Planning should include clarity of the type of anesthetic, the position of the patient, surgical approach, necessary equipment, and whether or not an x-ray will be required. It is helpful to the surgical team to have a written plan (see chapter 2.8). Implant removal can be challenging. Figure 2.14-3 illustrates a preoperative x-ray together with the subsequently removed implants. The broken nail with the broken locking screws had defeated two previous attempts at removal. Instead, a cable grip plate and a strut graft had been added at various times. Removal was only possible with careful planning.

Anticipate the unexpected

Problems are encountered in which locking screws from intramedullary nails or indeed the nails themselves unexpectedly turn out to be broken. Screws may break or screw heads may be stripped so they do not engage with the screwdriver. The implant may be deeply buried in bone or bony bridges may pass through the implant. Locking screw heads, particularly if slightly cross-threaded or over tightened may be permanently fixed to the implant so that the head will strip before the screw can be removed. It is not acceptable to undertake an operation for implant removal without anticipating these difficulties, as they are common. Specialist metal removal sets exist to deal with many of these problems and can be ordered in advance (Fig 2.14-4).

Fig 2.14-3a–b   The challenge of implant removal.
a   Before.
b   After.
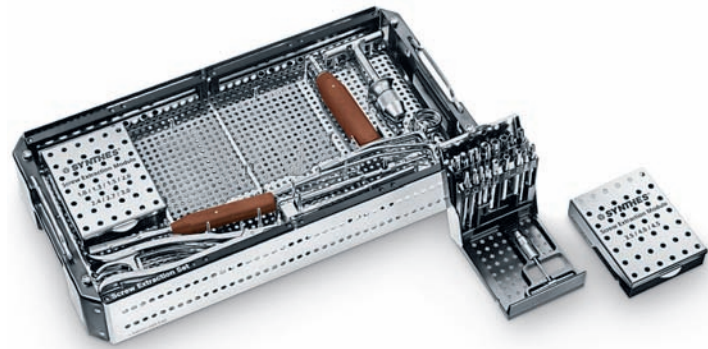
Fig 2.14-4   Screw extraction set with three modules for different screw sizes.

Operative technique

When planning is performed carefully, the operation should be straightforward. In general, it is important to use the same scar. Adjacent parallel scars look careless and may threaten a narrow bridge of skin between them. The principles of soft-tissue handling, anatomical dissection, and careful wound closure apply as in any other operation.

Aftercare

A postoperative x-ray is vital. Refracture is a recognized risk in this procedure. It is important to establish that the implants have been completely removed and that there was no intraoperative fracture. Thought should be given to activity levels, weight-bearing status, and the question of physiotherapy.

In the case of a weight-bearing bone with a large defect following implant removal, it may be prudent to arrange extended follow-up for 3–6 months, both to emphasize the risk of refracture to the patient and to confirm with x-ray that the bone has remodeled. It is difficult to assess the point at which the risk of refracture has passed by means of an x-ray. The period awaiting review may simply mean restricting loading until sufficient time has passed for the bone to strengthen.

2.14.5 Techniques for special problems

Broken bolts in locked intramedullary nails

The fragment attached to the head should be removed by a standard approach. Provided the nail has not moved, a Schanz screw or unthreaded Steinmann pin can be passed through the locking hole and gentle taps with a hammer will generally push the distal bolt fragment out of the nail and through the bone on the other side, where it can be retrieved through a separate incision.

If the nail has moved because the bolt broke, it may be necessary to withdraw the nail to the original position in which it was locked before using this technique.

Broken intramedullary nails

Hollow nails are usually relatively straightforward to remove. The sequence is as follows:
1. Remove any locking screws.
2. Approach the proximal end of the nail and remove it.
3. Pass a guide wire through the distal (remaining) fragment of nail.
4. Over ream the proximal part of the bone by at least 2 mm.
5. Pass a hooked wire, engage the distal fragment of the nail, and withdraw it using a T-wrench and slotted hammer.

Solid nails represent a much more difficult problem; however, they rarely break. When they do, the proximal portion can be removed in the standard way. If possible, drill and countersink the proximal end of the distal fragment to extract it. It may still not be possible to remove this nail fragment without windowing the bone, sometimes in several places, and cutting the nail into smaller fragments with a high-speed metal cutter.

Broken screws

The Synthes broken screw removal set contains in one tray the tools necessary for removal of screws broken in different ways (Fig 2.14-4). It also includes a metallic sheet printed with instructions for use. This is important as this set of instruments is usually unfamiliar to both surgeon and operating room personnel. It is strongly recommended that this set, or equivalent instrumentation, is available during all implant removal and particularly when problems might be reasonably anticipated.

Author   Graeme Groom

Head-sheared off

This is a common mode of failure for older implants. The implant, generally a plate, can usually be removed. The shaft of the broken screw can then be removed either with the dedicated pliers (Fig 2.14-5) from the broken screw removal set if it is prominent, or with a hollow extraction screw, by overdrilling, if it is buried (Fig 2.14-6). The recess in the head may strip so that the screwdriver will no longer engage. In this situation, the damaged screw head can be drilled with a high-speed harden drill bit. A conical extraction screw can then be used to engage and unscrew anticlockwise the damaged screw (Fig 2.14-7). As the screw head remains in place, the implant cannot be removed until the damaged screw is removed.

Cold-welded locking screw head

This represents a particular problem with titanium implants when the "weld" is frequently stronger than the force which can be applied by a screwdriver to the screw head before the screw head strips. This is common and requires metal-cutting equipment to cut the plate from the screw head. The screw can then be removed with suitable pliers. The alternative method of drilling out the screw head from the plate makes removal of the screw remnant more difficult.
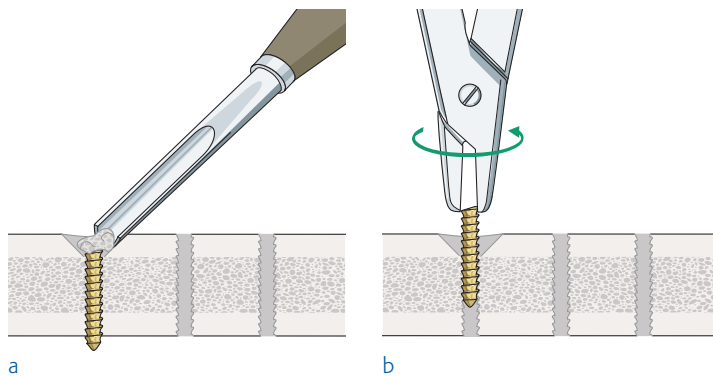
Fig 2.14-5a–b   Broken screw shaft removal.
a   The screw shaft is exposed with a gouge.
b   The screw shaft is extracted with the screw removal pliers.
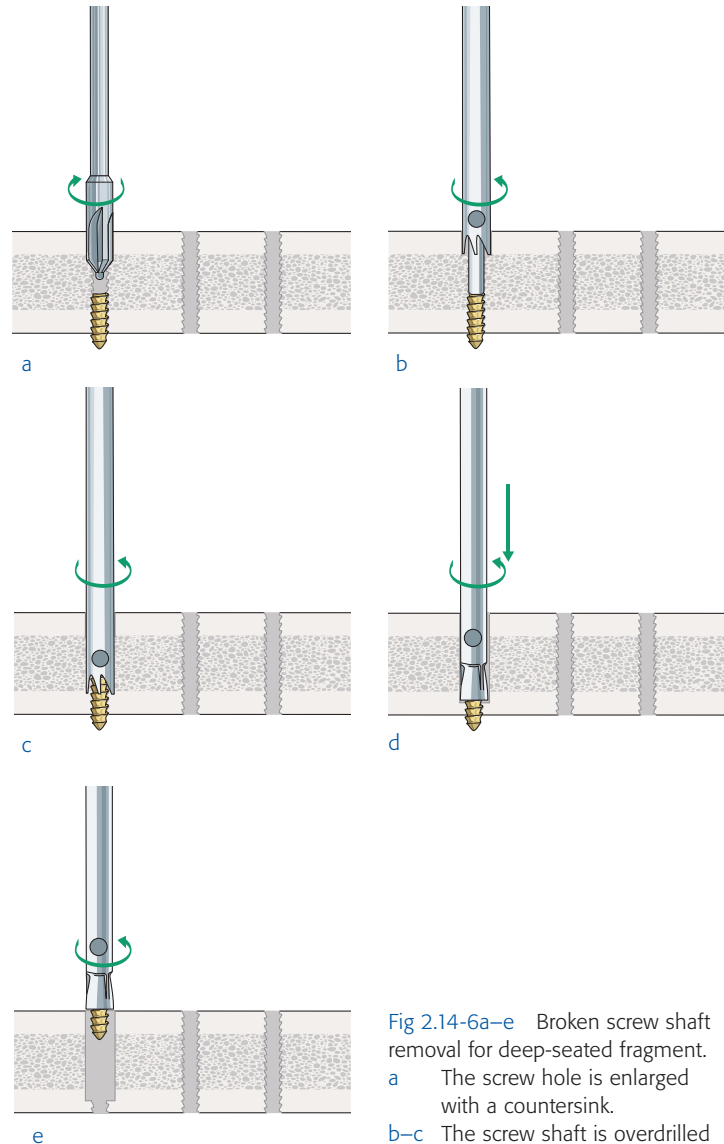
Fig 2.14-6a–e   Broken screw shaft removal for deep-seated fragment.
a   The screw hole is enlarged with a countersink.
b–c   The screw shaft is overdrilled anticlockwise with a hollow reamer, which has been assembled with a centering pin.
d–e   The extraction bolt is screwed anticlockwise over the threads of the broken screw and the fragment removed.

243

a

b
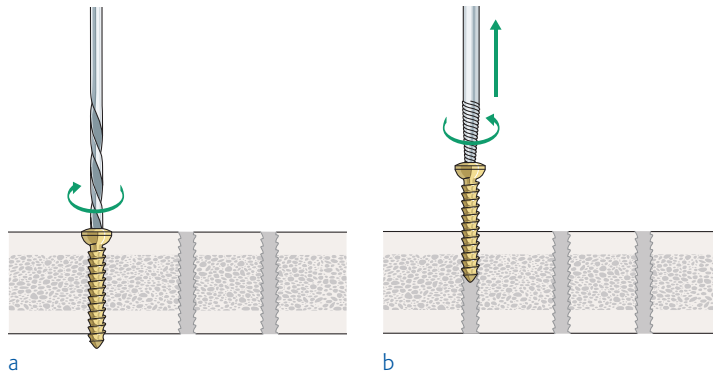
Fig 2.14-7a–b   Screw removal when recess is damaged.
a   The recess of the screw is "drilled out" with a high-speed drill bit (use HSS drill bit for steel screws and carbide drill bits for titanium screws).
b   A conical extraction screw is inserted. The extraction screw will grasp the recess when turning under pressure anticlockwise and can then be removed.

2.14.6   Conclusion

Implant removal should be carefully considered. The reasons for the operation should be clear. Planning should be meticulous. Difficulties are common and must be anticipated. Appropriate equipment must be available. Aftercare should be thoughtful.

3   Anatomical applications

3.1   Introduction

Authors   Susanne Bäuerle, Matthew Porteous

3.1   Introduction

The aim of section 3

This section of the book is intended to provide management, operative details, and techniques of fixation for the most common fractures in traumatology, specifically from the operating room personnel's (ORP) perspective. All operative steps are presented in sufficient detail to assist an ORP or a surgeon unfamiliar with the equipment.

Each chapter follows the same pattern. An introduction to a particular fracture is followed by one or more treatment options detailing the technique required to insert different implants.

We concisely list how ORP should prepare for a particular operation, with separate headings for the following:
- Introduction to the management of the fracture
- Preoperative patient preparation
- Instrument sets required
- Other equipment needed (eg, image intensifier)
- Anesthesia options
- Patient and x-ray positioning
- Skin disinfecting and draping
- Operating room set-up
- Photographs of implants and instruments for each step of the procedure

- Step-by-step procedure and technique details in text and illustrations
- Specific perioperative care
- Specific postoperative care
- ORP key points
- Surgeons key points

We propose that ORP and surgeons look closely at all the key points to better understand their potential concerns and difficulties while performing surgery; thus collaborating better as a team.

Teamwork is often defined as the actions of individuals, brought together for a common purpose, which subordinate the needs of the individual to the needs of the group.

If this always took place in the operating room setting, then the patients would really be treated very well. All members of a surgical team should put aside their individual needs to work toward the larger group and patient objectives. The better the interactions among team members and the work they complete, the more successful the patients with their fractures will be treated.

How to use this section

It is recommended that you read the introduction and then the chapter relevant to the operation for which you are preparing. Each surgical procedure is intended as a unit. Therefore some repetition of set-up and preparation details and illustrations are presented when these are the same for several procedures (eg, around the proximal femur).

The readers of this book are international and have to deal with very different facilities and resources in their own hospitals. It is intended that this book be used as a real handbook by OR staff and surgeons. You can make individual notes in the book reflecting the way a surgery is performed in your hospital, particularly with regard to the patient positioning, the OR set-up, and the instrumentation. This will enhance the value of the book as a reference tool for OR staff faced with an unfamiliar situation, such as sometimes occurs at night and weekends, and as a teaching aid for new staff.

Authors   Susanne Bäuerle, Matthew Porteous

General orthopaedic surgical instruments

This list shows the most frequently used general instruments in orthopaedic surgery.

Different manufacturers will provide a large selection of sizes and variations. A small representative generic selection is shown.
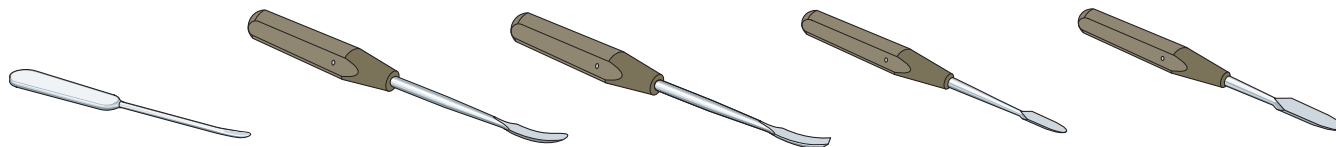
Periostal elevators (Fig 1a–e)
Elevators facilitate the exposure of fractures and careful dissection of fracture surfaces.
They are available with blunt and sharp blades, slightly curved or straight.
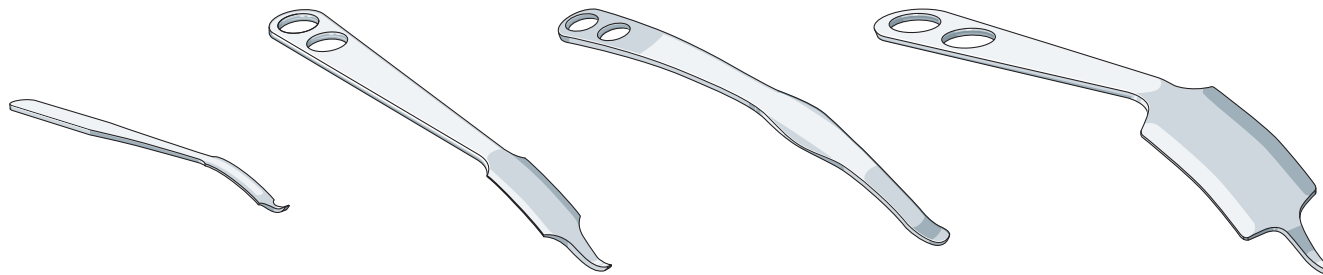
Retractors (Fig 2a–d)
The classic Hohmann style retractor is used to expose the bone surface. It is inserted around the bone to keep the soft tissues out of the way. Depending on the anatomical location, a smaller or larger retractor is chosen.
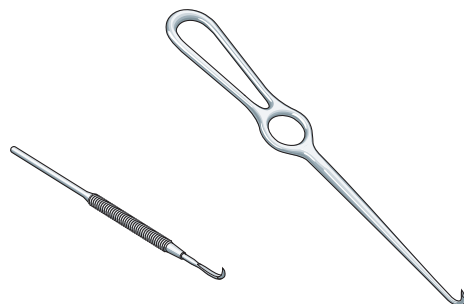
Bone hooks (Fig 3a–b)
A bone hook may be used to inspect fracture lines, reduce fracture fragments, or remove tissue debris.
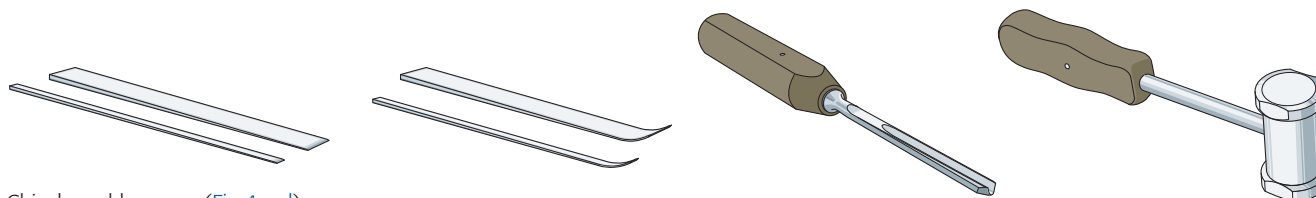
Chisels and hammer (Fig 4a–d)
Chisels may have straight, curved, or V-shaped blades. They may be used for decortication, osteotomies, or harvesting of bone grafts. Chisels are used with a hammer. The insertion of a nail or the impaction of K-wires also require a hammer.
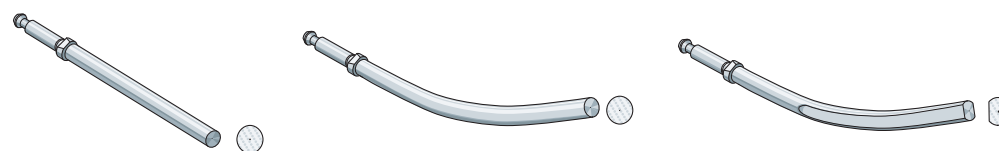
Cancellous bone impactors (handles not shown) (Fig 5a–c)
Impactors are used to pack cancellous bone grafts into the desired anatomical place. They may be used to reconstruct an articular surface. They are available in straight or curved versions with round or rectangular tips.
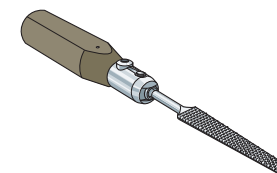
Bone rasp (Fig 6)
A rasp may be used for trimming rough ends of a bone graft or in case of an amputation.
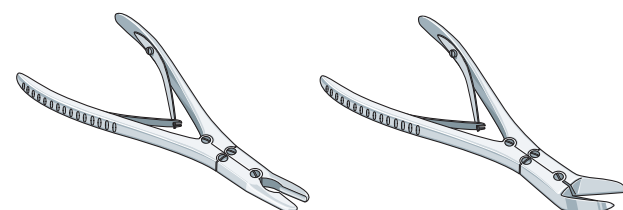
Bone cutting forceps (Fig 7a–b)
Bone cutting scissor-type forceps known as Luer and Liston may be used for bone dissection and/or reshaping bony fragment edges or contouring bone grafts.
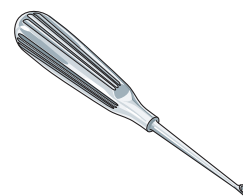
Bone curette (Fig 8)
This spoonlike-shaped instrument may be used to remove tissue or growths from a bony cavity. Bone curettes are often used in septique bone surgery.
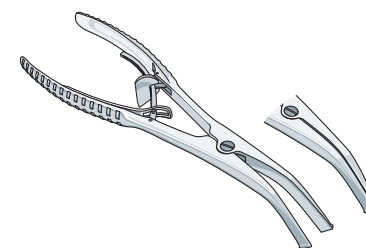
Bone spreader (Fig 9)
It may be used to distract a fracture for cleaning the surface or before interposition of a graft when performing a fusion type of surgery.

3.2   Clavicular fractures

Author   Peter Campbell

3.2   Clavicular fractures

Case

■   Diaphyseal wedge fracture of the clavicula

Introduction

Fractures of the clavicle are common injuries usually caused by a fall on an outstretched arm. Most clavicular fractures are treated nonoperatively, but many good indications for surgery exist. These include open fractures, fractures of the lateral third, fractures in association injuries to the scapula and nonunion. Although intramedullary nailing can be used for simple fractures of the shaft of the clavicle, plate fixation is the method of choice for most clavicular shaft fractures and both absolute and relative stability techniques can be used.

a

Müller AO/OTA Classification—diaphyseal clavicular fractures

15-B   clavicle, diaphysis

15-B
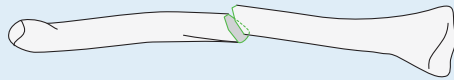
15-B1 simple
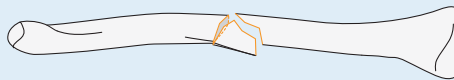
15-B2 wedge

15-B3 complex

Author   Peter Campbell
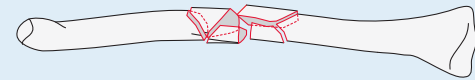
3.2.1   Clavicular fracture (15–B1): stabilization with reconstruction plate 3.5

Surgical management

- Stabilization with a reconstruction plate 3.5

Alternative implants

- Reconstruction locking compression plate 3.5 with locking or conventional screws
- LCP superior anterior clavical plate 3.5

1   Introduction
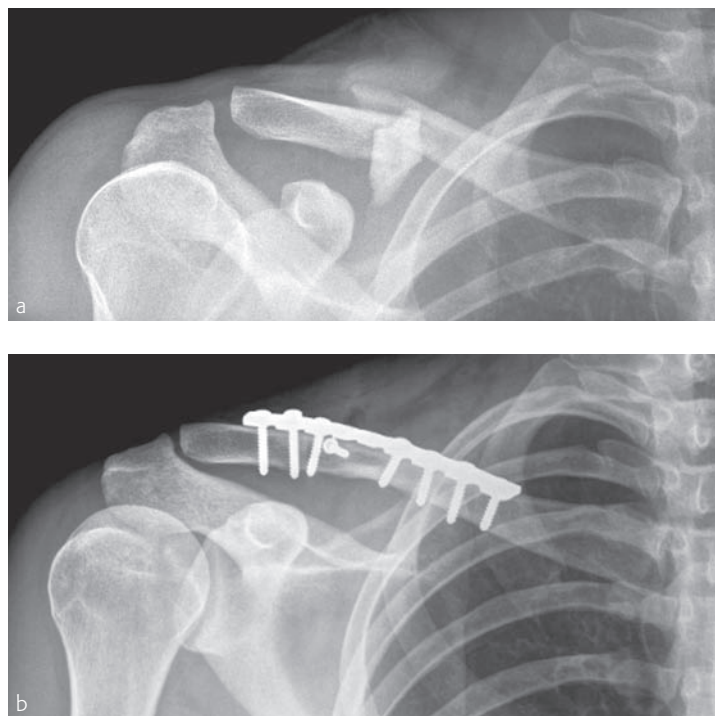
Fig 3.2-1a–b
a   Preoperative x-ray: wedge fracture of mid portion of the clavicle.
b   Postoperative x-ray: fixation with a lag screw and neutralization plate (reconstruction plate 3.5).

- Clavicular fractures are not included in the Müller AO Classification, but the Orthopaedic Trauma Association lists the clavicle as bone 15 and middle-third diaphyseal fractures as type B. These are subdivided as simple (15-B1), wedge (15-B2), or complex (15-B3).
- The usual mechanism of injury is a direct blow to the shoulder, forcing the lateral clavicle posteriorly and creating a fracture of the middle-third over the fulcrum of the first rib.
- The subclavian artery and vein, together with the brachial plexus run immediately behind the clavicle and are at risk—both at the time of fracture and during internal fixation.
- In all age groups, middle-third clavicular fractures will in most cases unite with simple conservative treatment. Treatment with a broad-arm sling or figure-of-eight bandage is equally effective in relieving discomfort and allowing early motion.
- Reported nonunion rates vary but are generally accepted to be less than 5%. Not all nonunions are symptomatic.
- Indications for primary surgical fixation of middle-third clavicular fractures include open fracture or impending skin perforation by a fracture fragment, associated injury to subclavian vessels, or brachial plexus and ipsilateral scapula neck fracture (floating shoulder).
- More relative indications would include clavicular fractures in patients with multiple injuries or bilateral clavicular fractures. Recent studies suggest that accurate reduction and fixation may have a better functional outcome than conservative treatment, but this remains controversial.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instruments
- Reconstruction plates and 3.5 mm cortex screws
- Corresponding bending pliers, irons, and templates
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Operating table with extension for head support
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general anesthesia.

Author   Peter Campbell

4   Patient and x-ray positioning

- Position the patient supine on the operating table.
- With the patient anesthetized, reconfigure the table in a beach chair position. Now the patient is in an upright position of approximately 45–50° with hips and knees flexed.
- Ideally, the head should be supported by a separate extension that allows the posterior aspect of the affected shoulder to be free of support. This allows comprehensive skin preparation and draping to the affected area; it permits the shoulder to be put through a full range of movement intraoperatively, and allows an unobstructed view of the fracture site with the image intensifier. A sandbag placed between the patient's shoulder blades will also enhance exposure of the posterior shoulder and aid reduction of the fracture (Fig 3.2-2).
- Placing the patient in this position also reduces intraoperative bleeding.
- The operating table is adjusted to the appropriate height for the surgical team. The image intensifier (when required) can be positioned to approach the shoulder from the top of the table.
- Care must be taken to fix the head and the endotracheal tube securely so they do not dislodge during surgery, while they are obscured under the drapes.
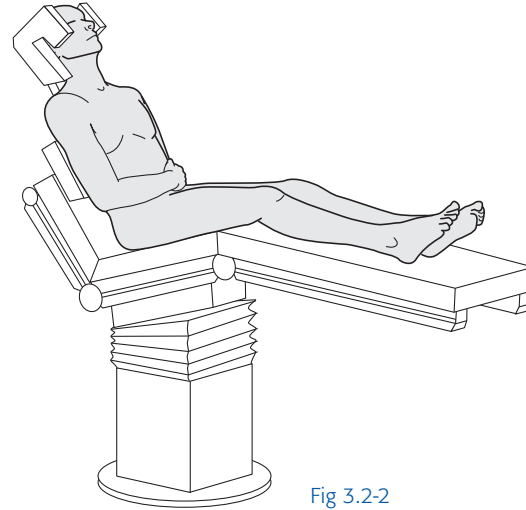
Fig 3.2-2

5   Skin disinfecting and draping

- Once the surgeon is satisfied with the position of the patient, disinfect the surgical area with the appropriate antiseptic. This area should include the base of the neck, sternum, pectoral area, upper arm, and posterior aspect of the shoulder. Particular attention should be given to disinfect the axilla (Fig 3.2-3).

- A plastic adhesive drape may be applied to the operative field.
- Drape the image intensifier.
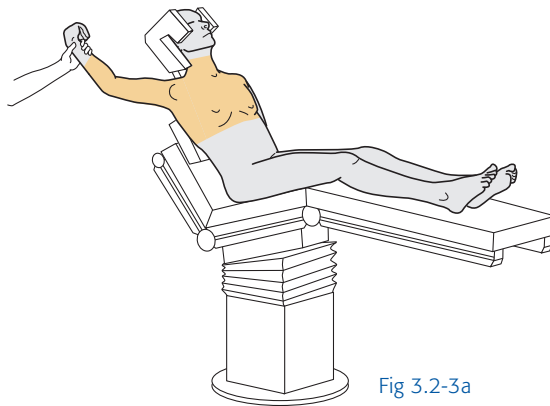
Fig 3.2-3a
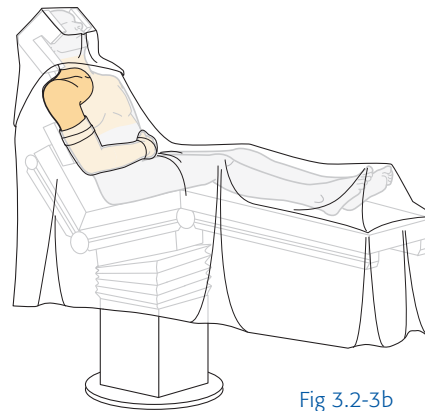
Fig 3.2-3b

6   Operating room set-up

- The anesthetist and anesthetic equipment should be situated at the foot of the table.
- The surgeon and assistant stand on the side of the injury.
- The ORP stands on the side of the injury.
- When required, the image intensifier can be introduced from the top of the table.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.2-4).

Fig 3.2-4

Author   Peter Campbell
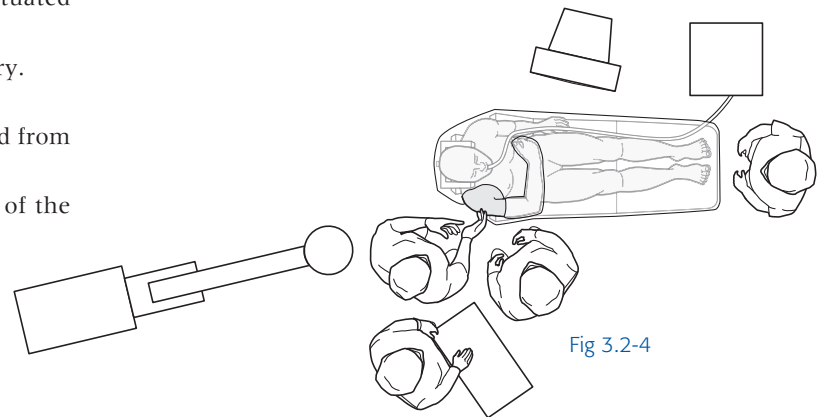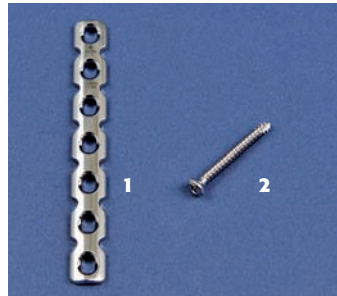
7   Instrumentation

Fig 3.2-5a   Implants
1.   Reconstruction plate 3.5, 7 holes
2.   Cortex screw 3.5 mm
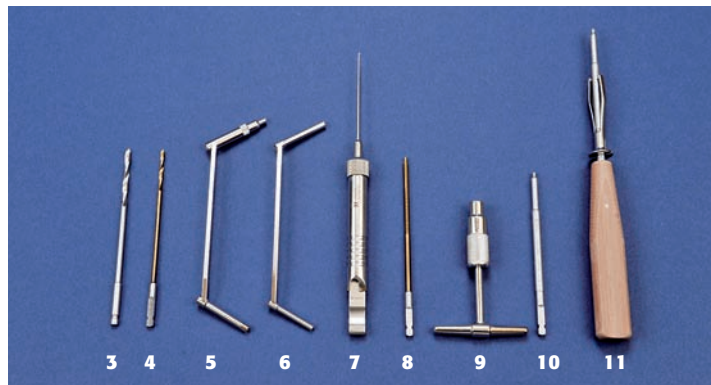
Fig 3.2-5b   Instruments for fracture fixation with reconstruction plate
and screws 3.5 mm
3.   Drill bit 3.5
4.   Drill bit 2.5
5.   Universal drill sleeve 3.5
6.   Double drill sleeve 3.5/2.5
7.   Depth gauge
8.   Tap 3.5
9.   T-handle
10.   Screwdriver shaft
11.   Screwdriver with holding sleeve 3.5
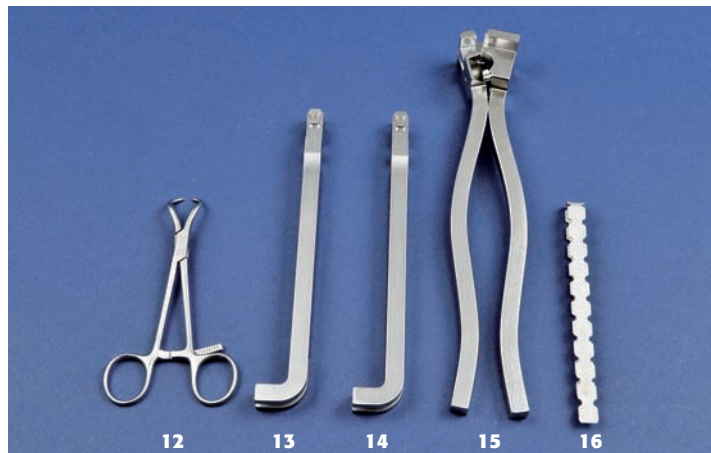
Fig 3.2-5c   Instruments for reduction and contouring
12.   Reduction forceps with points
13.   Bending iron for reconstruction plate 3.5
14.   Bending iron for reconstruction plate 3.5
15.   Bending pliers for reconstruction plate 3.5
16.   Bending templates for straight reconstruction plate 3.5

8   Procedure and technique–step-by-step

- Have a detailed plan for the operation drawn up by the surgeon.
- Incision: A "saber" (sagittal) incision directly over the fracture site onto the subcutaneous surface of the clavicle gives good cosmetic results and is appropriate for simple fractures. An incision parallel and just inferior to the clavicle provides a more extensive exposure for complex fracture patterns. This latter approach, however, has a tendency to lead to hypertrophic scar formation and has an increased risk of infraclavicular numbness.
- Expose the superior surface of the clavicle and remove the periosteum carefully from fragment ends, avoiding excessive stripping or devitalization.
- Expose the fracture site and wash it out.
- Reduce the fracture with gentle manipulation of fragments and hold it with the reduction forceps (Fig 3.2-6a).
- If the fracture pattern allows, a two-part fracture may be held by a single-lag screw before application of the plate. The plate is then applied as a protection plate (see chapter 2.4.2).
- To insert a lag screw drill a pilot hole through the near cortex with a 3.5 mm drill bit. Using the double drill sleeve (3.5/2.5) as a centralizer, drill through the far cortex using a 2.5 mm drill bit. Countersink the hole, measure the length of the screw needed using a depth gauge, and tap the bone using the (gold-colored) 3.5 mm cortical tap. Insert the appropriate 3.5 mm cortex screw (Fig 3.2-6b).
- Contour the selected (usually 6- or 7-hole) plate using the corresponding template. Due to the shape of the clavicle longer reconstruction plates in particular need to be contoured in all three planes. The use of the reconstruction plate bending tool is illustrated (Fig 3.2-6c).
- Fix the plate to the clavicle using 3.5 mm cortex screws, with at least three screws each side of the fracture if possible. Drill the hole with a 2.5 mm drill bit, measure the depth, and tap the bone with the cortical tap. Finally insert the appropriate 3.5 mm cortex screw (Fig 3.2-6d).
- Be extremely careful when drilling the far cortex, or using the tap or the depth gauge because of the close proximity of the subclavian vessels and brachial plexus.
- For more complex fracture patterns, a bridging-plate technique may be more appropriate (see chapter 2.4.6). This requires indirect reduction using a longer plate, spanning the fracture fragments, and avoiding individual fragment dissection.
- Take and save copies of final x-rays.
- Close the wound.

Author   Peter Campbell
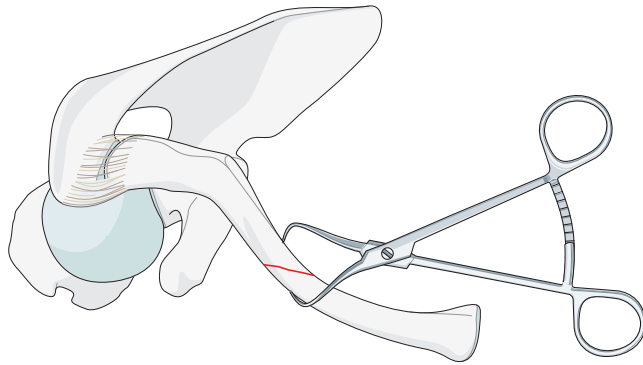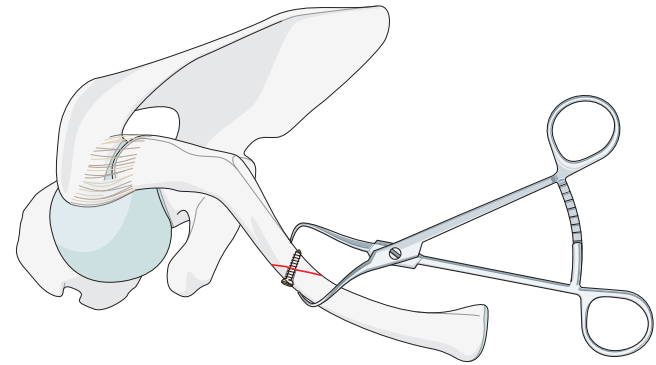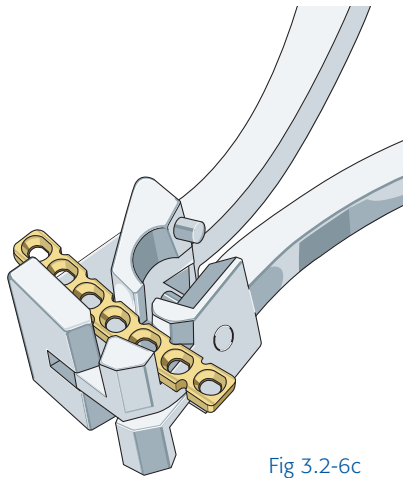
Fig 3.2-6a

Fig 3.2-6b

Fig 3.2-6c
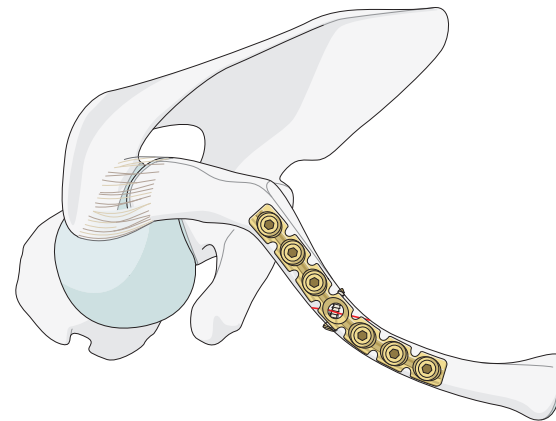
Fig 3.2-6d

9 Specific perioperative care

- Be careful with pressure areas and ensure elbow is well padded to protect the ulnar nerve.
- Ensure the head is secured and stable in the support ring and is tilted away from the injured side.
- Ensure anesthetic tubing is routed and secured in such a way that it will not be pulled or leaned on during surgery.

10 Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of implant, unless adequate hard or electronic copies were taken from the image intensifier.
- Patient should avoid placing full weight on the affected upper limb, ie, pushing up on the arm of a chair, until progress of healing is confirmed.
- Pendulum exercises should be started on the first postoperative day and continued regularly after discharge. Rest the arm in a sling under the clothes for the first week, and unclothed for hygiene and exercises. The sling can then be worn outside the clothes for 2 more weeks, at which stage active-assisted exercise can be started to improve range of movement, aiming for active elevation and abduction to 90° by 6 weeks, and a full range of movement within 10–12 weeks.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check each screw length.
- Clean drill bit and tap after each use.
- Document and reorder all implants used.

Author   Peter Campbell

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- The illustrated case above assumes the fracture is oblique and suitable for lag screw insertion before the plate is applied. Depending on the fracture orientation, it may be necessary to apply the plate in compression mode and then insert the lag screw through the plate (see chapter 2.4.2).
- If the fracture pattern is short, oblique or transverse, a lag screw cannot be used at all and the plate will have to be used as a compression plate (see chapter 2.4.2).

- If the fracture pattern is multifragmentary, compression may not be desirable and the plate will be used as a bridging plate.
- Ensure satisfactory patient set-up.
- Carefully handle soft tissues and fracture fragments to maintain blood supply and avoid devitalization.
- Carefully contour the appropriate plate to match shape of the clavicle.
- Avoid over penetration of the far cortex with drill bit or screw to minimize risk of damage to the brachial plexus or subclavian vessels.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.3   Proximal humeral fractures

Author David Limb

3.3 Proximal humeral fractures

Implants and surgical technique

- Proximal humeral internal locking system (PHILOS)
- Proximal humeral nail (PHN)
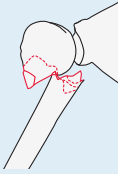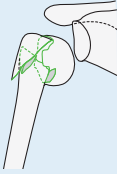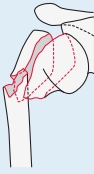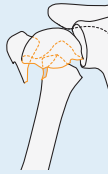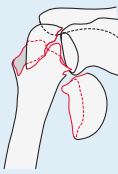
Cases

- Three part fracture of the proximal humerus (11-B1)
- Two part fracture of the proximal humerus (11-A3)

Introduction

- According to the Müller AO/OTA Classification, proximal humeral fractures are divided into:
  - 11-A extraarticular unifocal
  - 11-B extraarticular bifocal
  - 11-C articular
- The widely used Neer classification mainly looks at the degree of dislocation and at the number of fragments (especially the two tuberosities).
- Adequate imaging to understand the fracture configuration and to plan surgery is mandatory. A computed tomographic (CT) scan is often helpful.
- Fractures of the proximal humerus are mainly seen in two groups of patients. One group is mostly elderly, frail patients with osteoporosis. These are low-energy injuries. The other group is young, fit patients with good bone stock. The injuries are higher energy, frequently resulting from sports injuries.

- Fractures of the proximal humerus may disrupt the blood supply to the humeral head and can lead to avascular necrosis.
- Displacement of the humeral head or tuberosity fragments relative to the shaft of the humerus will limit and weaken movement at the shoulder. There is debate over what constitutes acceptable displacement for nonoperative treatment. Historically, a fragment is considered displaced if it is separated by >1 cm or rotated by 45°.
- Anatomical reduction of these fractures can be difficult or impossible, although the quality of the reduction is a major factor in determining the stability of the fixation and the functional outcome.
- Reduction and internal fixation of even displaced fractures in the elderly with osteoporosis has not yet been proved to give a better outcome than nonoperative treatment, and hemiarthroplasty may be a valid alternative.

Müller AO/OTA Classification—proximal humeral fractures

| 11-A1 | 11-A2 | 11-A3 | 11-B1 | 11-B2 | 11-B3 | 11-C1 | 11-C2 | 11-C3 |

11-A extraarticular unifocal fracture
11-A1   tuberosity
11-A2   impacted metaphyseal
11-A3   nonimpacted metaphyseal

11-B extraarticular bifocal fracture
11-B1   with metaphyseal impaction
11-B2   without metaphyseal impaction
11-B3   with glenohumeral dislocation

11-C articular fracture
11-C1   with slight displacement
11-C2   impacted with marked displacement
11-C3   dislocated

Author   David Limb

3.3.1   Displaced three part proximal humeral fracture (11-B1): stabilization with PHILOS plate

Surgical management

- Stabilization with PHILOS plate

Alternative implants

- Proximal humeral nail
- Wires and 4.0 mm cannulated screws using a minimally invasive technique
- Small fragment plates and 3.5 mm screws with tension band sutures

1   Introduction
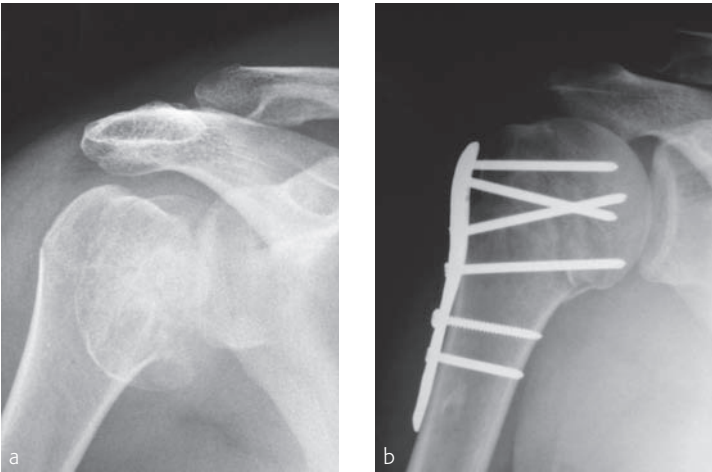
Fig 3.3.1-1a–b
a   Preoperative x-ray: displaced two part proximal humeral fracture.
b   Postoperative x-ray: fixation with PHILOS plate.

- Displaced humeral head fractures in younger patients requires accurate reduction and fixation to obtain good shoulder function.
- Advantages of the PHILOS plate are the locking head screws (LHS) which provide angular stability with less risk for pull out. Also the plate is not pressed against the bone surface, thus preserving the delicate vascular supply.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:

- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:

- PHILOS instrument set
- PHILOS plates
- Small fragment instruments and conventional screws 3.5/4.0 mm
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Torque limiting attachment 1.5 Nm

Equipment:

- Standard table allowing beach chair position
- Positioning accessories to assist beach chair position
- Small table to use as armrest
- Image intensifier
- X-ray protection devices for personnel and patient

3   Anesthesia

- General anesthesia
- Local nerve block
- Combination of nerve block and light general anesthesia

Author   David Limb

4   Patient and x-ray positioning

- The torso of the patient is brought into the 30° beach chair position after the anesthetist has secured the oral tube and has moved to the opposite side of the patient.
- If using a standard table with a shoulder table attachment, place a pillow beneath the calves, tilt table head down by 10º, and then elevate the patient's torso.
- If using a multifunctional table, ensure the head is secured and that a section of the table can be removed on the side of the injured shoulder, allowing for better access and imaging.

Break the table at the hips and bring the patient into a 30° sitting position. Position a padded table to rest the arm on it in 45° abduction, relaxing the deltoid muscle (Fig 3.3.1-2a).

- Position the image intensifier from the head end, with a tilt of about 20–30º to allow a good AP view of the shoulder (Fig 3.3.1-2b).
- Ensure that satisfactory x-ray views of the shoulder can be obtained before starting surgery.
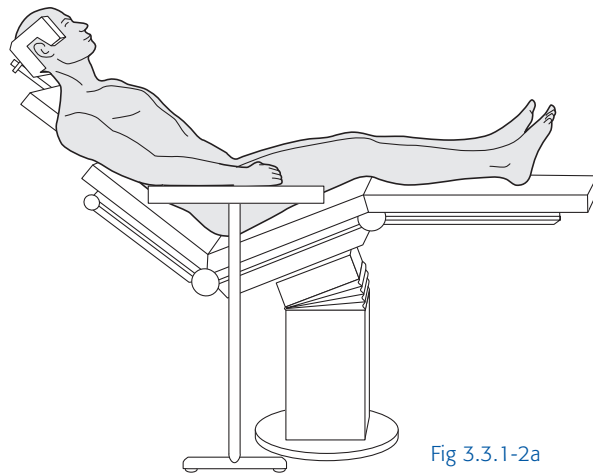
Fig 3.3.1-2a
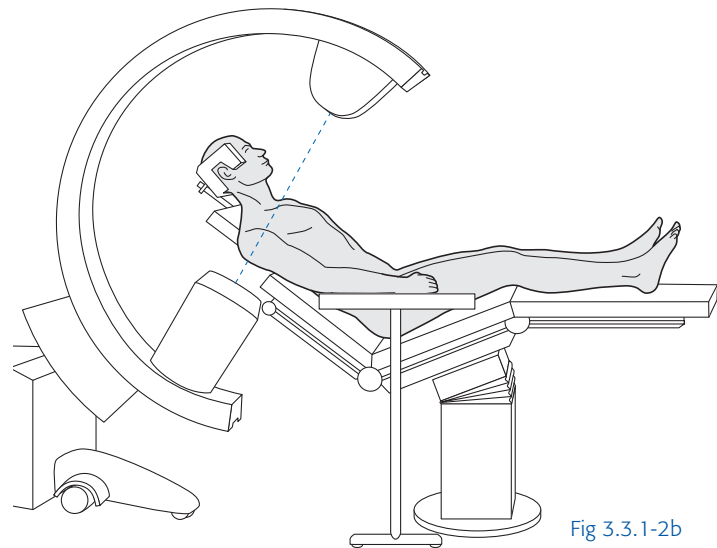
Fig 3.3.1-2b

5 Skin disinfecting and draping

- Disinfect the entire arm and shoulder from the neck to the fingertips with an assistant holding the arm (Fig 3.3.1-3a).
- Cover the hand and forearm in a waterproof stockinette.
- Apply a U drape with the split facing the axilla. The apex of the U is on the lateral chest wall and the two tails are stuck down anterior and posterior to meet at the root of the neck (Fig 3.3.1-3b).
- Drape the image intensifier.
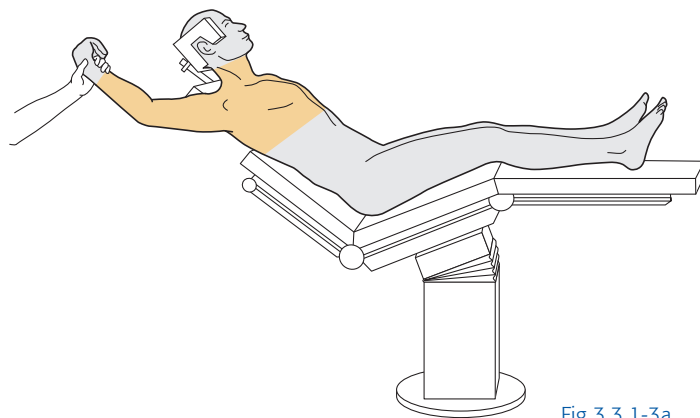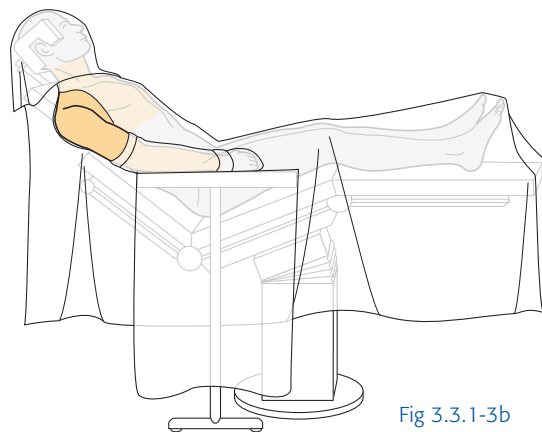
Fig 3.3.1-3a

Fig 3.3.1-3b

6 Operating room set-up

- The surgeon stands facing the patient's shoulder, adjacent to the operating table and the axilla or he positions himself between the patient and the abducted arm facing the axilla.
- The assistant can stand behind the patient's shoulder.
- The ORP sets up between the two surgeons.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.3.1-4).
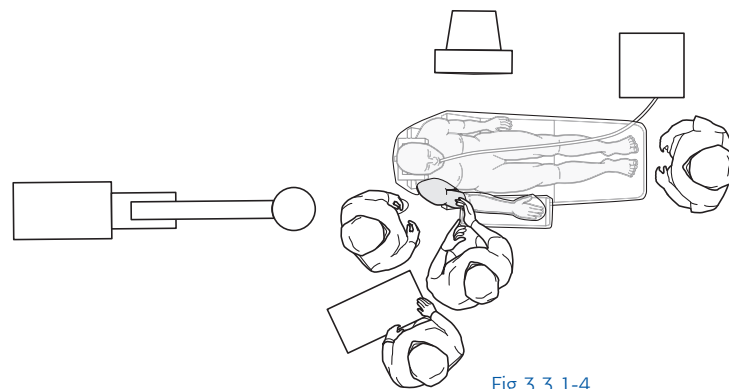
Fig 3.3.1-4

7   Instrumentation

Fig 3.3.1-5a   Implants
1.   PHILOS plate
2.   Locking head screw 3.5 mm
3.   Cortex screw 3.5 mm, self-tapping

Fig 3.3.1-5b   Instruments for preliminary fixation
4.   Aiming device
5.   Screwdriver for aiming device
6.   Centering sleeve 6.0/5.0 mm for aiming device
7.   Drill sleeve 5.0/2.9 mm for aiming device
8.   Centering sleeve for 1.6 mm K-wires for aiming device
9.   1.6 mm K-wires, 150 mm
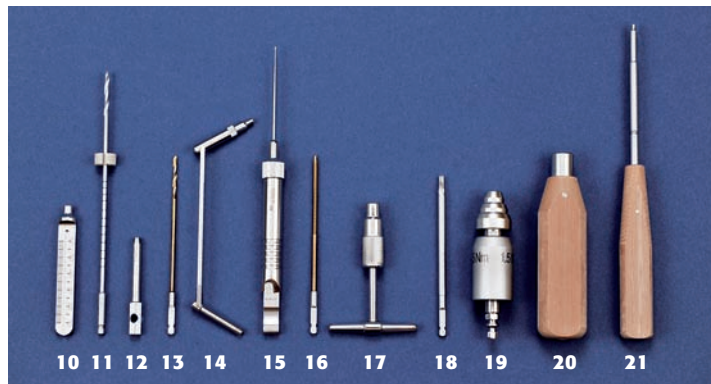
Fig 3.3.1-5c   Instruments for fracture fixation with PHILOS plate
10.   Measuring device for K-wires
11.   LCP drill bit 2.8 mm
12.   LCP drill sleeve 2.8 mm
13.   Drill bit 2.5 mm
14.   Universal drill sleeve (3.5/2.5)
15.   Depth gauge
16.   Tap 3.5 mm
17.   T-handle
18.   Screwdriver shaft
19.   Torque limiter 1.5 Nm
20.   Handle for torque limiter
21.   Screwdriver

8 Procedure and technique—step-by-step

- Make an anterior incision, using the deltopectoral approach to the shoulder, between the anterior border of deltoid and the pectoralis major muscle. Preserve the cephalic vein.
- Expose fracture lines and remove the hematoma. Do not detach soft tissues from the fracture fragments, so as not to further disturb their blood supply.
- Secure the rotator cuff as it inserts onto any tuberosity fragments with strong sutures and attach them to small clamps. These sutures can be used to manipulate the fragments and later to fix the tuberosities and rotator cuff to other bone fragments or to the plate (Fig 3.3.1-6a).

- Reduce the humeral head with an elevator inserted through the fracture gap, hold the position with one or two 2.0 mm K-wires, and check the result with the image intensifier before applying the PHILOS plate.
- Mount the aiming device to the selected PHILOS plate.
- Slide the plate in along the humeral shaft and apply it to the reduced humeral head. Check the position with a K-wire placed through the proximal guide hole of the aiming device. This wire should rest on top of the humeral head.
- Draw the sutures from the rotator cuff through the small holes on the PHILOS plate (Fig 3.3.1-6b).
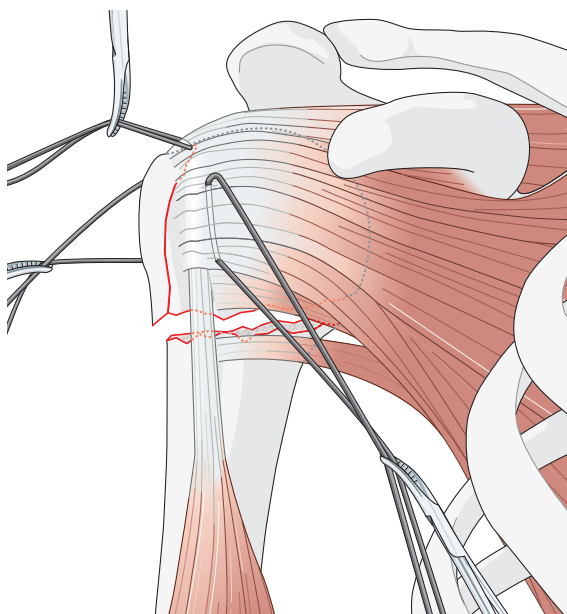
Fig 3.3.1-6a
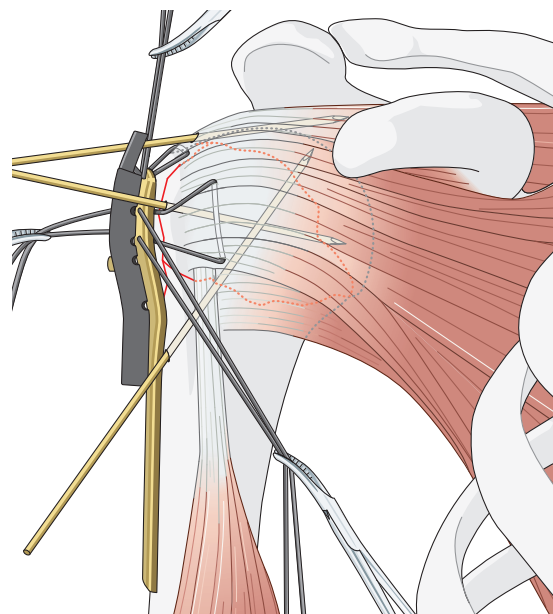
Fig 3.3.1-6b

Author David Limb

- The first screw for positioning the plate should be a conventional 3.5 mm cortex screw through the oval hole into the humeral shaft (Fig 3.3.1-6c).
- Drill a 2.5 mm hole using the universal drill guide pushed into the nonthreaded part of the plate hole, measure the length, and then insert the appropriate length self-tapping cortex screw.
- Check reduction and position of the PHILOS with the image intensifier.
- If the position is not perfect untighten the screw slightly, which will allow you to move the plate proximally and distally on the humerus. Once a perfect position has been obtained, fully tighten the screw.
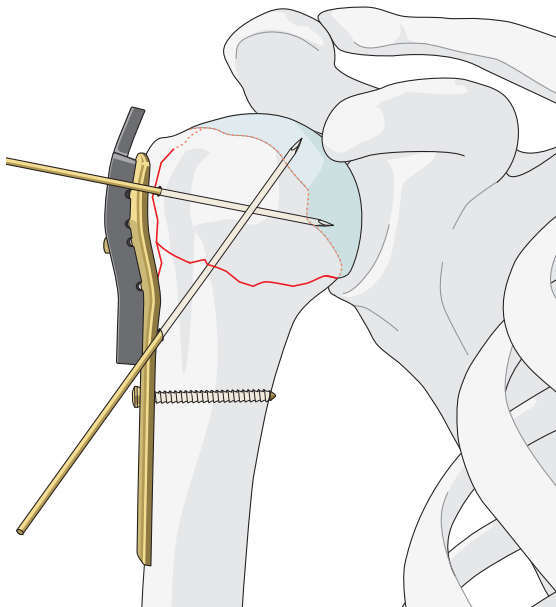
- A temporary K-wire can be inserted into the humeral head where it is intended to place a screw, using the triple guide, which is placed in the appropriate hole in the aiming block (Fig 3.3.1-6d).
- Check the position of the K-wire with the image intensifier.
- Locking head screws (LHS) 3.5 mm can now be used to fix the humeral head fragments. Temporary K-wires may be used to define the screw length with the direct measuring device and will be replaced one by one by a LHS of appropriate length. These screws should be at least 5 mm short of the articular surface to reduce the risk of screws penetrating the joint in case of postoperative bone collapse.
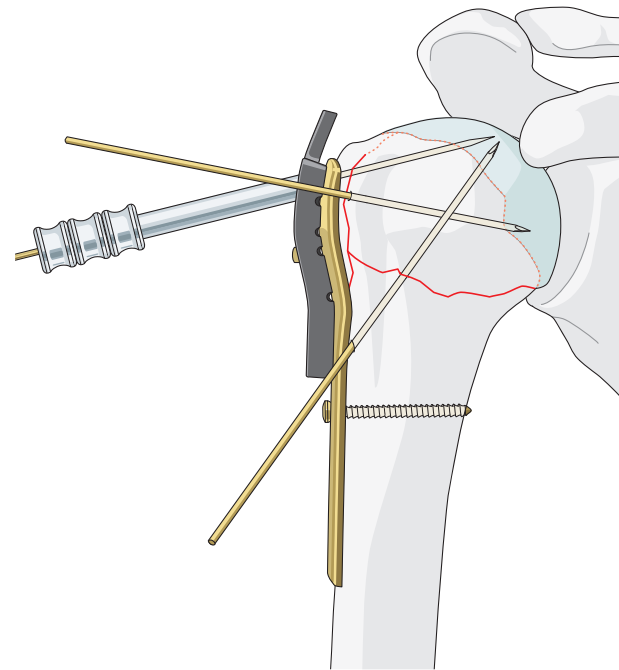
Fig 3.3.1-6c

Fig 3.3.1-6d

- Remove the K-wire and the inner K-wire centering sleeve of the triple guide.
- Drill a hole with the 2.8 mm drill bit up to the required screw length by direct reading off the calibration of the drill bit (Fig 3.3.1-6e).
- Remove the drill sleeve from the centering sleeve.
- Insert the appropriate length self-tapping 3.5 mm LHS through the centering sleeve with the power drill. Tighten the last few turns by hand using the handle with the 1.5 Nm torque-limiting attachment (Fig 3.3.1-6f).

- The number of screws used in the humeral head will depend on bone quality and fracture configuration, but is usually between four and six.
- Fixation of the plate to the humeral shaft may be done with self-tapping 3.5 mm cortex screws. LHS may be appropriate in poor-quality bone.
- For self-tapping 3.5 mm screws, drill the holes using the 2.5 mm drill bit in the spring-loaded 2.5 mm universal drill guide with the tip pressed in against the nonthreaded portion of the plate hole. The screw length is measured and the appropriate length screw is inserted and tightened.
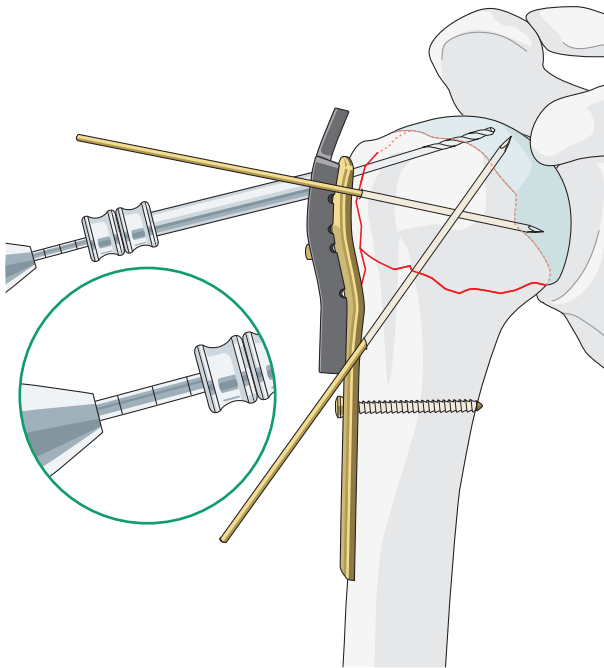
Fig 3.3.1-6e
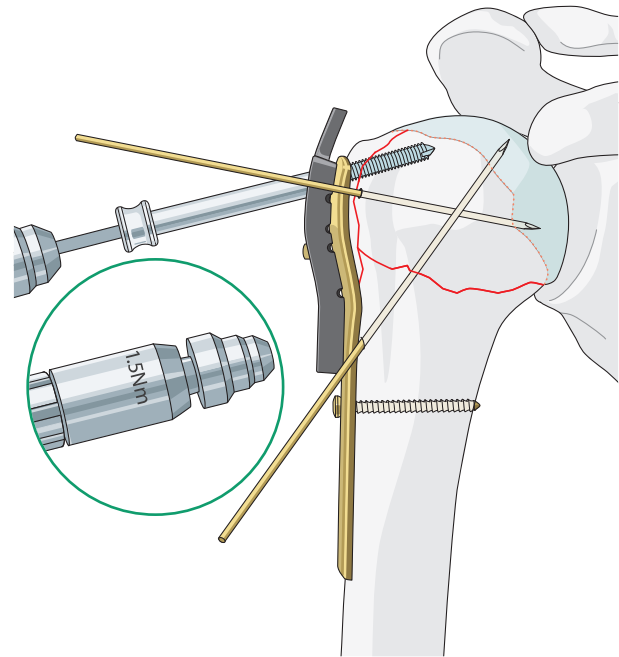
Fig 3.3.1-6f

- Insertion of LHS in the shaft area is done with the 2.8 mm drill sleeve securely screwed into the threaded portion of the screw hole.
- Drill the hole with the 2.8 mm drill bit, remove the sleeve, measure the length, and insert the LHS as described above.
- Tuberosity fragments and parts of the rotator cuff can be tied to the plate using the sutures that have been inserted into the rotator cuff placed through the small plate holes (Fig 3.3.1-6g).
- Check fixation with the image intensifier in both AP and axial views.
- The deltopectoral interval should close spontaneously as the retractors are removed and does not usually require suturing. Check that the cephalic vein has not been damaged.
- Close the wound.

Further information is available on AO Teaching video 20211: The Proximal Humerus Internal Locking System PHILOS.
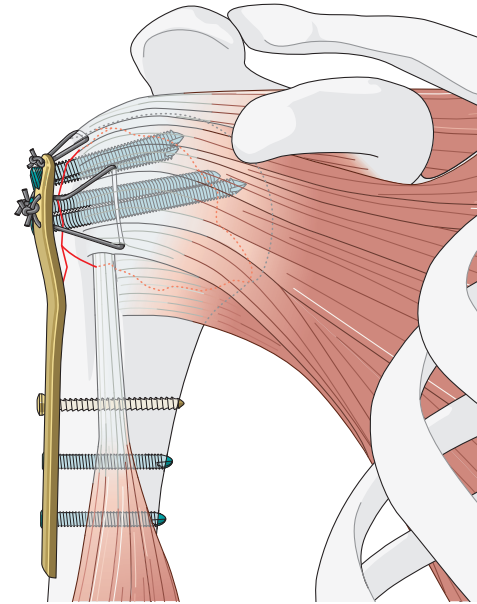
Fig 3.3.1-6g

9 Specific perioperative care

- Ensure the head of the patient is secure and anesthetic ventilation lines are protected throughout the procedure.
- Ensure that the arm is rested on a well-padded support to protect the ulnar nerve.
- Ensure that sterility of the operative field is maintained as the image intensifier is maneuvered around the operative site.

10 Specific postoperative care

- The arm is fixed to the body with a Velpeau or similar bandage until the patient is fully awake and able to cooperate.
- If stable fixation has been achieved the arm should be taken out of the sling as early as possible to allow passive- and active-assisted exercises.
- Timing of active use and loading of the limb depends on the bone quality, on the soft tissues, and should be tailored to each patient by the operating surgeon.
- Prolonged shoulder immobilization will inevitably lead to stiffness and long-lasting pain.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Only 1.6 mm K-wires can be used with the plate.
- For fracture fixation independent of the plate, other K-wire sizes may be used.
- Prepare thick sutures to grab the rotator cuff and adjoining bone fragments.
- Be prepared for application of different types of screws.
- A long PHILOS plate may be required.
- Document and reorder all implants used.

12 Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Check patient position and free access of image intensifier to the shoulder in both planes before draping.
- Check the reduction of the fracture and correct plate position on the humeral head before inserting any screws. Only limited adjustments can be made once the first cortex screw has been placed into the oval plate hole on the humeral shaft portion.
- If the humeral shaft is medially displaced, gradually tighten the first cortex screw placed into the distal fragment. It will pull the shaft to the plate. The screw may be too long and needs to be replaced with a shorter one.
- Always use the aiming device for screw placement into the humeral head.
- Ensure no screws penetrate the articular surface of the humeral head.
- Always tighten the locking screws by hand using a torque-limiting screwdriver. Failure to do so may result in jamming the screw heads in the plate making screw removal difficult.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author David Limb

3.3.2 Two part extraarticular bifocal proximal humeral fracture (11-A3): stabilization with proximal humeral nail (PHN)

Surgical management

- Stabilization with proximal humeral nail (PHN)

Alternative implants

- Small fragment plates and 3.5 mm screws with tension band sutures
- PHILOS plate
- Wires and 4.0 mm cannulated screws using minimal invasive technique

1 Introduction
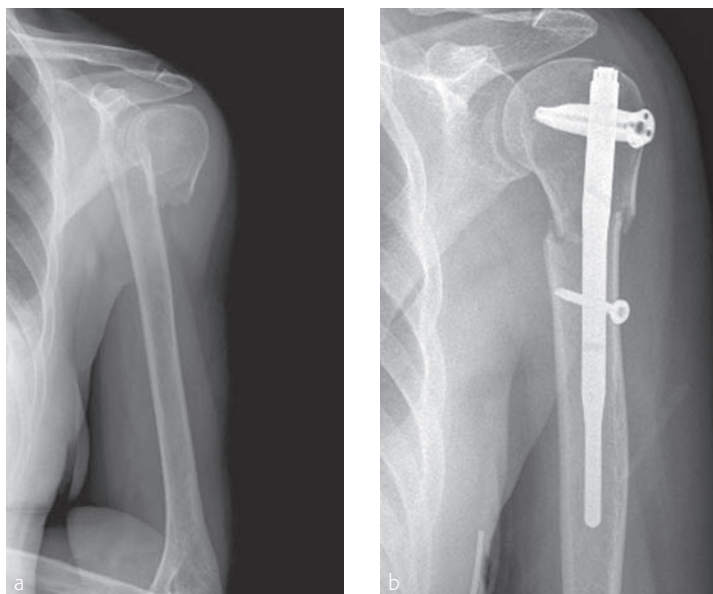
Fig 3.3.2-1a–b
a   Preoperative x-ray: displaced transverse extraarticular fracture of the proximal humerus.
b   Postoperative x-ray: stabilization with a proximal humeral nail (PHN).

- Intramedullary nails have a mechanical advantage over plates in providing stable fixation, particularly in two part fractures. This is offset by the disadvantage of problems related to maintaining the stability of tuberosities and head after fixation, and problems related to the rotator cuff which can be damaged by nail insertion.
- Nail fixation lends itself to a minimally invasive approach. With a specifically designed nail for the proximal humerus it is also possible to stabilize tuberosity fragments if they can be reduced or are in an acceptable position after nail insertion.
- In elderly patients with poor-quality bone, hemiarthroplasty or nonoperative treatment may be preferred.
- Reduction and internal fixation of displaced fractures in the frail and elderly has not yet been proven to give a better outcome than nonoperative treatment.

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2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation:
- Proximal humeral nail set
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Reaming attatchment for drill

Equipment required:
- Standard table allowing beach chair position
- Table and positioning accessories to assist beach chair position
- Small table to use as armrest
- Image intensifier
- X-ray protection devices for personnel and patient

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3 Anesthesia

- General anesthesia
- Local nerve block
- Combination of nerve block and light general anesthesia

Author   David Limb

4   Patient and x-ray positioning

- Beach chair position is recommended.
- The torso of the patient is brought into the 30° beach chair position after the anesthesiologist has secured the oral tube and has moved to the opposite side of the patient.
- If using a standard table with a shoulder table attachment place a pillow beneath the calves, tilt table head down by 10º, and then elevate the patient's torso.
- If using a multifunctional table ensure the head is secured and that a section of the table can be removed on the side of the injured shoulder allowing for better access and imaging. Break the table at the hips and bring the patient into a 30° sitting

position. Place a padded table to rest the arm on it in 45° abduction, relaxing the deltoid muscle (Fig 3.3.2-2a).
- Position the image intensifier from the head side, with a tilt of about 20–30º to allow a good AP view of the shoulder (Fig 3.3.2-2b).
- Ensure that satisfactory views of the shoulder can be obtained before starting surgery.
- It is also possible to insert the PHN with the patient in supine position on a radiolucent table, with the shoulder either overlying a removable section in the table or overhanging on a radiolucent arm board.
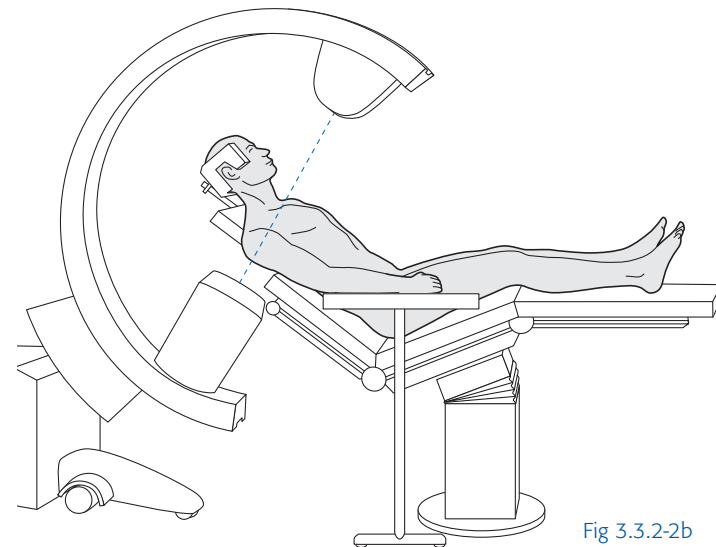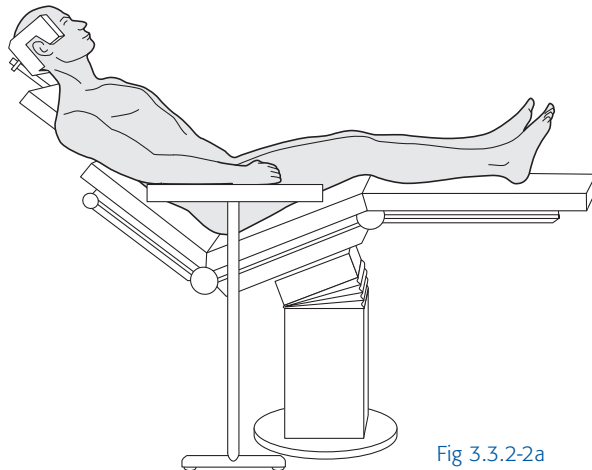
Fig 3.3.2-2a

Fig 3.3.2-2b

5 Skin disinfecting and draping

- Disinfect the entire arm and shoulder from the neck to the fingertips with an assistant holding the arm (Fig 3.3.2-3a).
- Cover the hand and forearm in a waterproof stockinette.
- Apply a U drape with the split facing the axilla. The apex of the U is on the lateral chest wall and the two tails are stuck down anterior and posterior to meet at the root of the neck (Fig 3.3.2-3b).

- Rest the arm on a sterile-draped side table in a position of neutral rotation (forearm pointing parallel to the table and not across the patient's chest).
- Drape the image intensifier.
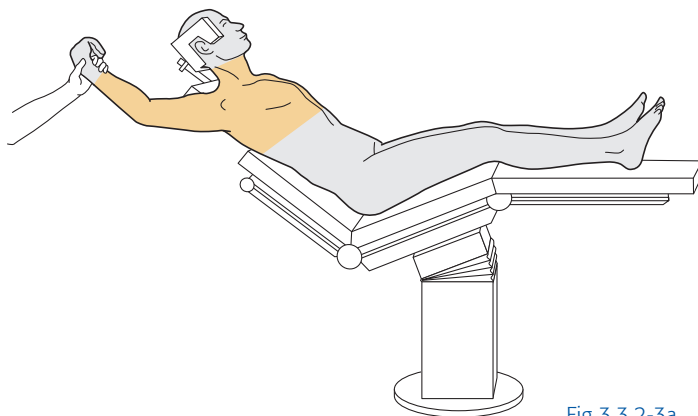
Fig 3.3.2-3a
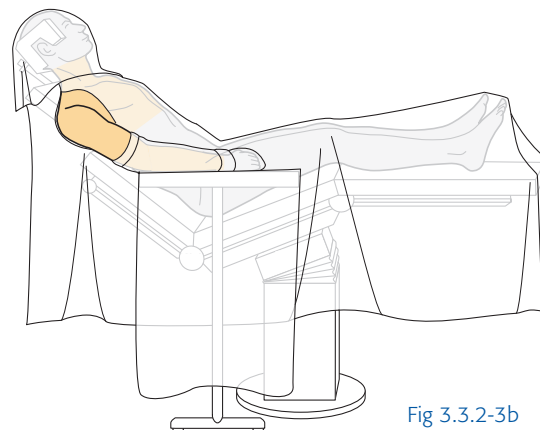
Fig 3.3.2-3b

6 Operating room set-up

- The ORP and surgeons stand facing the patient's shoulder, adjacent to the operating table and the axilla.
- The assistant can stand behind the patient's shoulder initially, but will have to move adjacent to the surgeon once the image intensifier is brought into position.
- The scrub nurse sets up between the two surgeons.
- The anesthetist is at the head on the opposite side or at the foot end of the table.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.3.2-4).
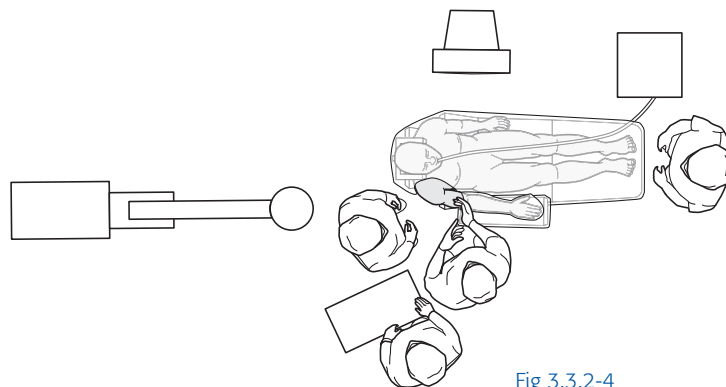
Fig 3.3.2-4

7   Instrumentation
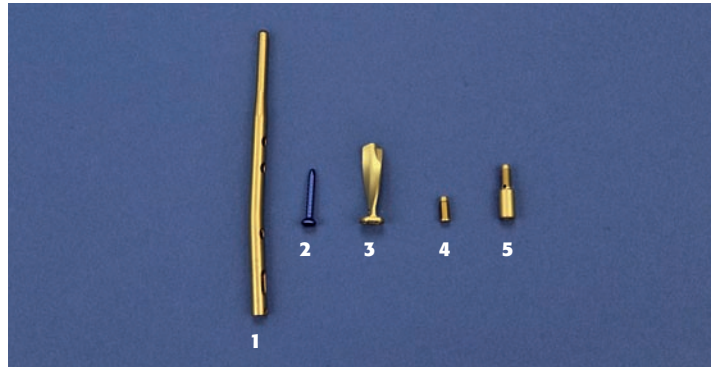
Fig 3.3.2-5a   Implants
1.   PHN 7.5 mm
2.   Locking bolt 3.9 mm
3.   Spiral blade
4.   End cap 0 mm
5.   End cap with extension
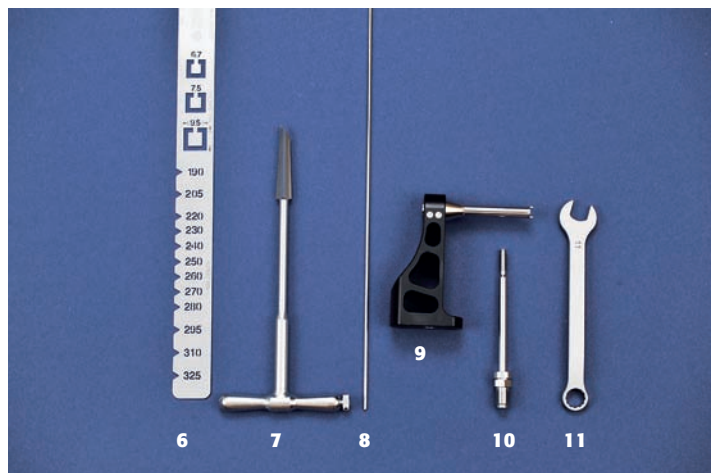
Fig 3.3.2-5b   Instruments for nail insertion
6.   Radiographic ruler
7.   Awl
8.   K-wire 2.5 mm, 280 mm, trocar tip
9.   Insertion handle
10.   Connecting screw
11.   Combination wrench 11 mm
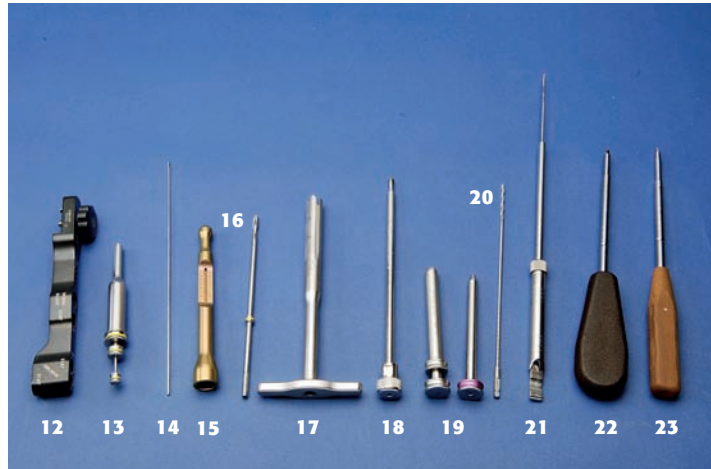
Fig 3.3.2-5c Instruments for proximal and distal locking
12. Aiming arm
13. Triple drill sleeve assembly (protection sleeve 14.0/4.5 mm with trocar 2.0 mm and drill sleeve 4.5/2.0 mm)
14. K-wire 2.0 mm, 230 mm, threaded tip
15. Direct measuring device for spiral blades
16. Cannulated drill bit 4.5 mm
17. Inserter for spiral blades
18. Connecting screw
19. Triple drill sleeve assembly (protection sleeve 11.0/8.0 mm with trocar 8.0 mm and drill sleeve 8.0/2.7 mm)
20. Drill bit 2.7 mm
21. Depth gauge for locking bolts
22. Screwdriver large (for locking bolts and for end cap with extension)
23. Screwdriver small (for end cap 0 mm)
      Note (not in picture): universal chuck with T-handle
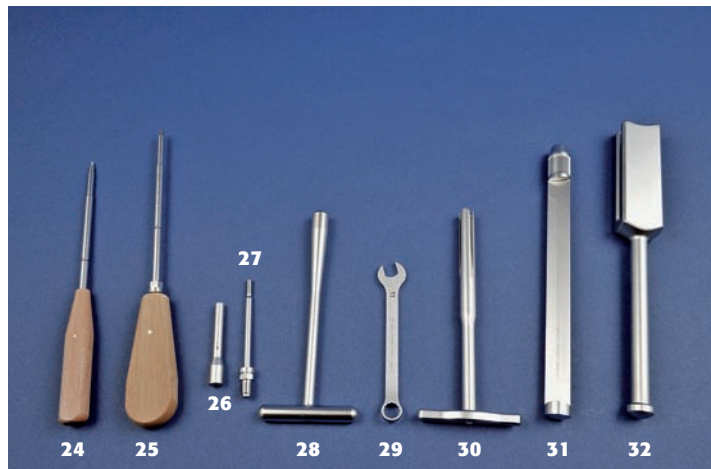
Fig 3.3.2-5d Instruments for implant removal
24. Screwdriver small (for end cap 0 mm)
25. Screwdriver large (for locking bolts and for end cap with extension)
26. Connecting piece for extraction
27. Connecting screw
28. Socket wrench 11 mm
29. Combination wrench 11 mm
30. Inserter for spiral blade
31. Inserter/extractor
32. Slotted hammer

Author David Limb

8 Procedure and technique—step-by-step

- Allow the arm to loosely rest on the side table with the shoulder in slight extension, bringing the humeral head and its tuberosities anteriorly.
- Incise the skin starting at the anterior edge of the acromion about 3–4 cm distally in direction of the humerus. Be aware of the axillary nerve that circles the humerus about 5 cm distal to the head.
- Split the deltoid to expose the rotator cuff beneath as it inserts into the tuberosities. Do not detach any of the deltoid insertion into the acromion.
- Identify the correct entry point with the patient in appropriate position (Fig 3.3.2-6a–b) at the greater tuberosity in line with the humerus shaft and insert a guide wire 2.5 mm using the universal chuck and T-handle (Fig 3.3.2-6c).
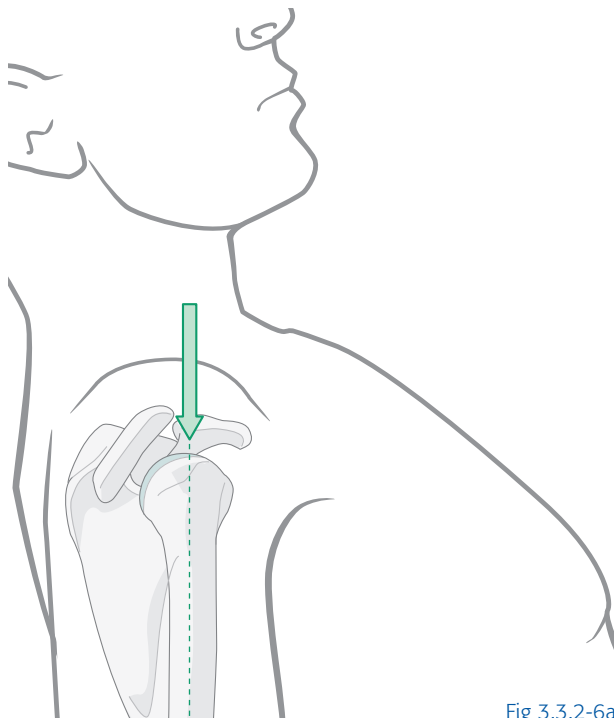
Fig 3.3.2-6a
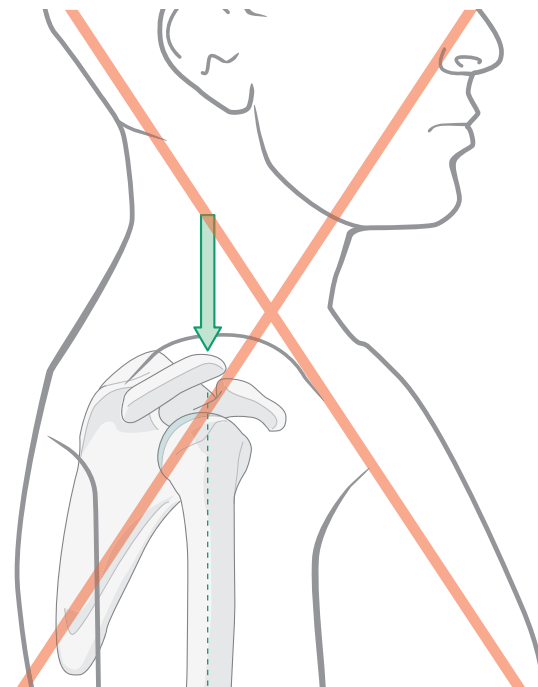
Fig 3.3.2-6b

- Check its position with the image intensifier. On the AP view the entry point is at the edge of the superior articular margin of the humeral head, and on the lateral view the wire should be seen to cross the head.
- Split the fibers of the rotator cuff to insert the nail with minimal damage to the tendons. Insert stay sutures into the divided margins of the tendon to facilitate repair of the rotator cuff during closure. Persistent rotator cuff tears are common in the elderly, and make the approach to the entry point easier.

- Slide the cannulated awl over the 2.5 mm guide wire to open the nail entry point (Fig 3.3.2-6d).
- Determine the length and diameter of the nail with the radiographic ruler.
- Mount the insertion handle on the PHN of appropriate length and diameter with the connecting screw. Ensure that the nail curvature (convex side) points away from the insertion handle (Fig 3.3.2-6e).
- Reduce the fracture by gentle traction on the arm and insert the nail by manually twisting it back and forth until it passes across the fracture site (Fig 3.3.2-6f).
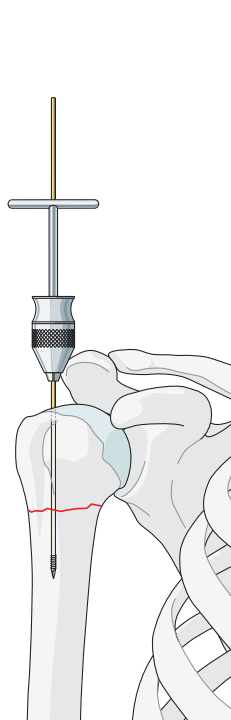
Fig 3.3.2-6c
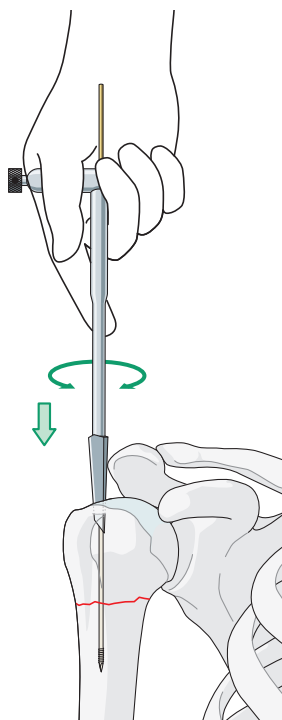
Fig 3.3.2-6d
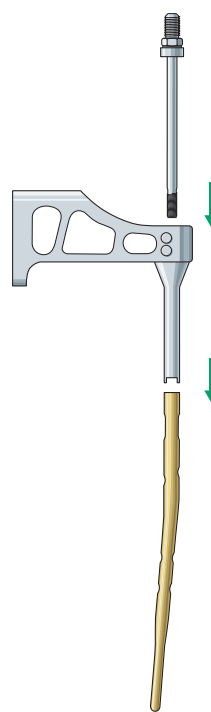
Fig 3.3.2-6e

Fig 3.3.2-6f

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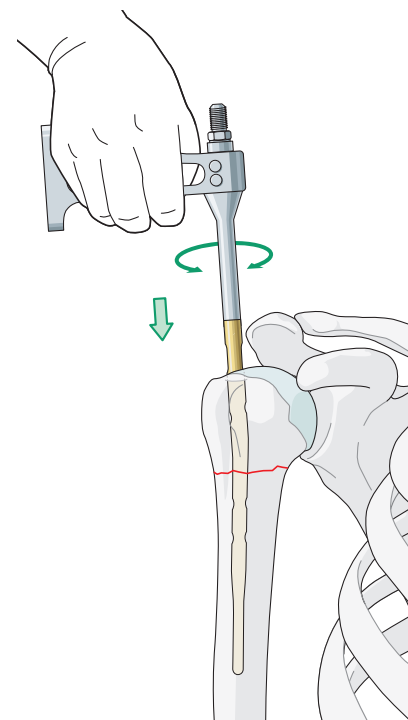
- Do not use a hammer, as it may lead to cracks in the humerus or even a fracture.
- Insert the nail so that the proximal end lies just beneath the surface of the humeral head. It must not project as this will prevent repair of the rotator cuff and cause shoulder pain.

Proximal locking

- Lock the nail proximally first with a spiral blade or screws. The spiral blade obtains better purchase in poor-quality bone and is described.
- Attach the aiming arm for spiral blade to the insertion handle. The humeral head is normally retroverted. Therefore swivel the aiming arm 20º anteriorly to ensure the blade enters the center of the humeral head.
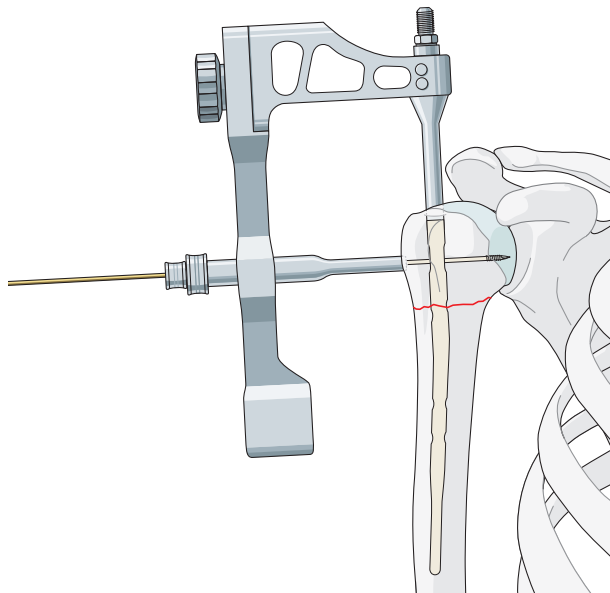
- Assemble the three-piece trocar combination and pass it through the uppermost hole of the aiming arm.
- Make a stab incision in the skin and bluntly split the deltoid muscle to insert the trocar against the bone of the humeral head. Be aware of the axillary nerve.
- Remove the trocar and insert a 2 mm K-wire into the humeral head. Check its position with the image intensifier and make sure it does not penetrate the articular surface of the humerus (Fig 3.3.2-6g).
- Measure the depth of the wire with the direct measuring device for spiral blade (Fig 3.3.2-6h).
- Remove the inner sleeve of the tissue protector.
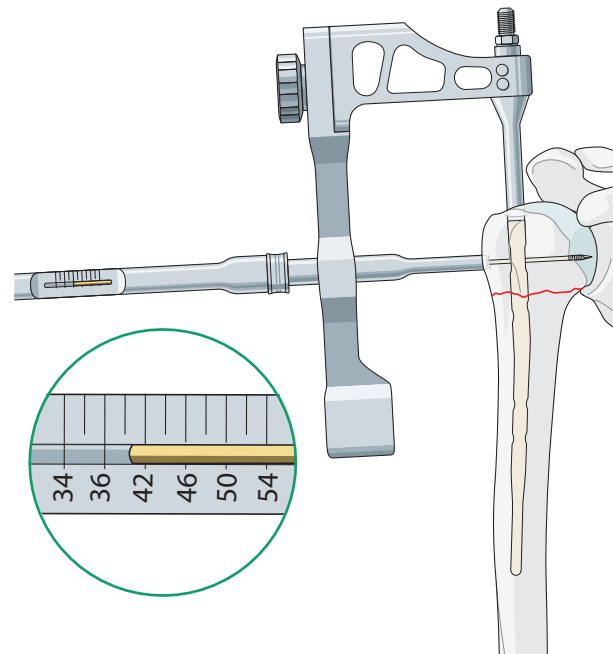
Fig 3.3.2-6g

Fig 3.3.2-6h

- Drill with the cannulated 4.5 mm drill bit for the spiral blade to the automatic stop. Remove the drill bit, making sure the K-wire does not get stuck in the cannulation of the drill (Fig 3.3.2-6i).
- Insert the connecting screw into the inserter for spiral blade and mount spiral blade of appropriate length on the insertion handle.
- Remove the protection sleeve.
- Introduce the spiral blade and inserter over the K-wire and through the aiming arm down to the lateral cortex (Fig 3.3.2-6j).

- Align the T-handle of the inserter parallel with the aiming arm.
- Apply gentle hammer blows to the connecting screw to advance the spiral blade into the humeral head. As the blade advances the T-handle will rotate through 90°.
- Check the position of the spiral blade with the image intensifier.
- Unscrew the inserter handle and remove the K-wire.
- The proximal blade fixation may be increased by a single-angulated 3.9 mm proximal locking bolt inserted through the aiming arm, using the same technique and instruments as for the distal locking bolt.
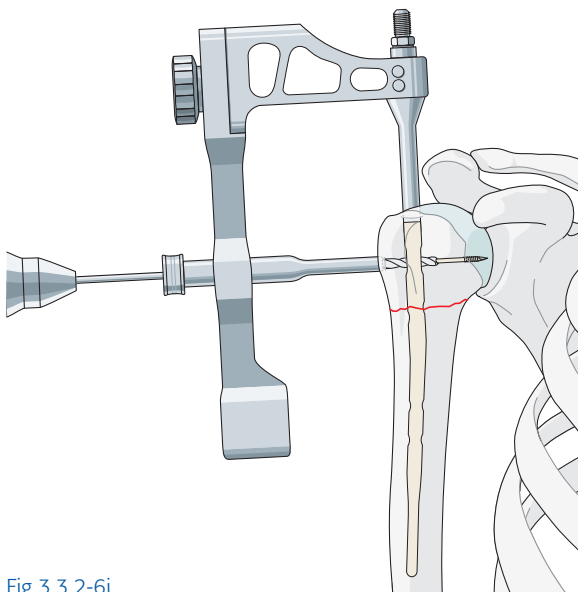
Fig 3.3.2-6i

Fig 3.3.2-6j

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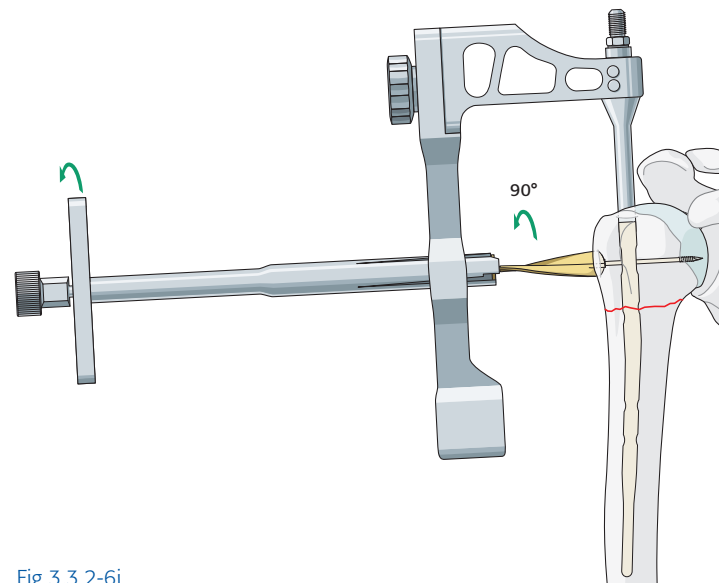
Distal locking

- Before performing distal locking, ensure the fracture is not distracted. Compression should be applied to the fracture by gently pushing up on the elbow to close any gap.
- Insert the two-piece trocar combination (protection sleeve and trocar 8 mm) into the hole of the aiming arm.
- Make a stab incision and insert the trocar down to the bone.
- Exchange the trocar for the 8.0/3.2 mm drill sleeve.
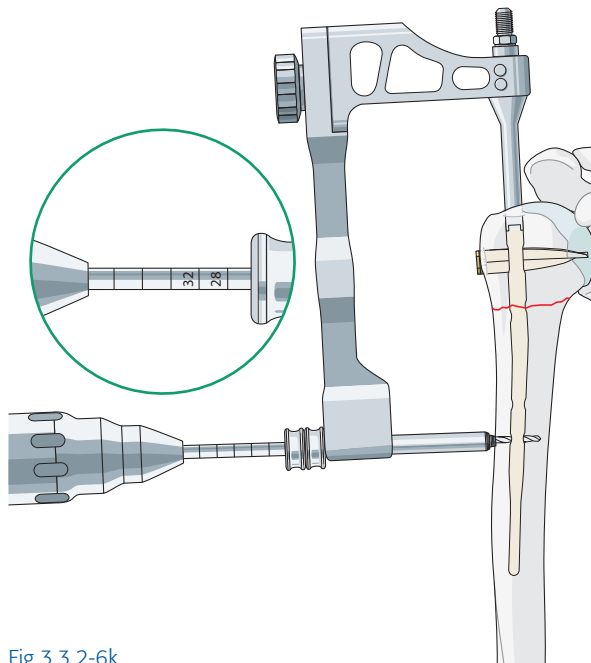
- Drill both cortices with a 3.2 mm drill bit and measure the bolt length with the depth gauge. Add 2 mm to the measurement (Fig 3.3.2-6k).
- Remove the drill sleeve and insert the appropriate length locking bolt (Fig 3.3.2-6l).
- A second locking bolt should be inserted using the same technique.
- Check the position of the blade and screws with the image intensifier.
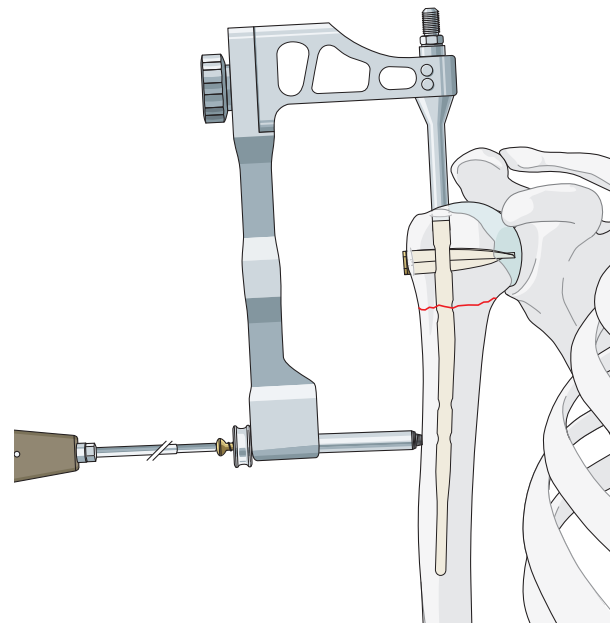
Fig 3.3.2-6k

Fig 3.3.2-6l

- Finally lock the blade in the nail with an end cap placed into the threaded hole at the top of the nail. The selected end cap should be left flush with the surface of the humeral head (Fig 3.3.2-6m).
- Close the rotator cuff tendons carefully over the entry point using the stay sutures. The deltoid fibers will fall back side-to-side when the self-retaining retractor is removed.
- Close the wound.
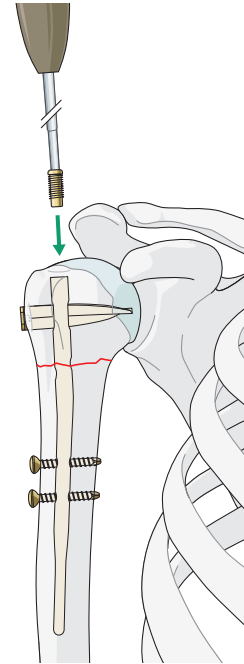
Fig 3.3.2-6m

9 Specific perioperative care

- Ensure the head is secure and anesthetic ventilation lines are protected.
- Ensure that the arm is rested on a padded table to protect the ulnar nerve.
- Ensure sterility of the operative field is maintained as the image intensifier is maneuvered around the wound.

10 Specific postoperative care

- A shoulder immobilizer is worn until the patient has fully recovered from the anesthetic and is able to cooperate.
- If stable fixation has been achieved, passive- and active-assisted exercises should be started immediately.
- The timing of active use and loading of the arm depends on the bone quality and soft tissues, and is tailored to each patient by the operating surgeon.
- Prolonged shoulder immobilization will inevitably lead to stiffness and pain.

Author   David Limb

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Ensure new guide wires of the correct size are used each time. Damaged wires may bind in the cannulated awl or drill bit.

- Do not confuse the 2.5 mm K-wire for awl and 2.0 mm K-wire for blade.
- Discard guide wires after use.
- Flush and preclean (stylet and brush) cannulated instruments after use.
- Mount the nail correctly onto the insertion handle.
- Document and reorder all implants used.

12   Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Check patient position and that of the image intensifier for good imaging of the shoulder in both planes before draping.

- Take care of the axillary nerve when using the deltoid-split approach and during insertion of the spiral blade.
- Ensure the nail does not protrude above the bone after insertion.
- Suture the rotator cuff carefully over the nail entry point. Failure to do this may cause persistent shoulder discomfort.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.4   Humeral shaft fractures

Author   Rogier Simmermacher

3.4   Humeral shaft fractures

Implants and surgical technique

- Unreamed (solid) humeral nail (UHN)
- LC-DCP 4.5 narrow
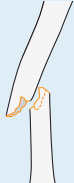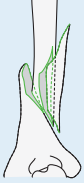
Cases

- Humeral shaft fracture (12-C2)
- Humeral shaft fracture (12-A1)

Introduction

- According to the Müller AO/OTA Classification humeral diaphyseal fractures are classified as:
  - 12-A simple fracture
  - 12-B wedge fracture
  - 12-C complex fracture
- These fractures account for about 1% of all fractures.
- Direct trauma and rotational forces in sports and motor vehicle injuries are common causes of humeral shaft fractures in younger people. In the elderly, the fracture is usually caused by a simple fall on the arm.
- In mid-shaft fractures and fractures at the junction of the upper two-thirds and lower third, the radial nerve may be in danger and its function must always be carefully assessed and documented before any treatment.
- Nonoperative treatment, eg, using functional bracing, is a widely accepted treatment option for closed fractures.
- Absolute indications for surgery are:
  - most open fractures
  - fractures associated with vascular injury
  - floating elbow or shoulder
  - bilateral humeral fracture is not an absolute indication but a relative indication
  - fractures in pathological bone
  - secondary nerve injury—nerve damage occurring as a result of closed reduction
- Relative indications for surgery include primary nerve injury, obesity, and patient preference.
- Fractures in the middle third may be treated with closed intramedullary nailing (inserted either in an antegrade or retrograde direction) or plates (inserted either open or with the MIPO technique). Many surgeons prefer to apply plates for most humeral shaft fractures.
- Fractures in the proximal and distal thirds are often easier and safer to stabilize with a plate, especially if there is an intraarticular extension.
- The long-term outcome for nailing as well as plating is similar, so that the selection of the type of fixation greatly depends on the preference and experience of the surgeon.
- External fixation as a definitive treatment is an option but only exceptionally advised, since it is cumbersome for the patient and difficult to care for.

Müller AO/OTA Fracture Classification—humeral shaft

| 12-A1 | 12-A2 | 12-A3 | 12-B1 | 12-B2 | 12-B3 | 12-C1 | 12-C2 | 12-C3 |

12-A simple fracture
12-A1   spiral
12-A2   oblique ($\geq 30°$)
12-A3   transverse ($< 30°$)

12-B wedge fracture
12-B1   spiral wedge
12-B2   bending wedge
12-B3   fragmented wedge

12-C complex fracture
12-C1   spiral
12-C2   segmental
12-C3   irregular

Author   Rogier Simmermacher

3.4.1   Humeral shaft fracture (12-C2): stabilization with intramedullary humeral nail (UHN)

Surgical management

- Stabilization with intramedullary humeral nail (UHN—unreamed humeral nail 7.5 mm) inserted without reaming in retrograde direction

Alternative implants

- Expert humeral nail
- Plates:
  - LC-DCP 4.5 narrow or broad
  - LCP 4.5/5.0 narrow or broad

1   Introduction

- Most closed humeral shaft fractures can be treated nonoperatively by bracing or splinting. Indications for surgery must be carefully evaluated.
- Surgery should be performed within 8–10 days after injury, unless there is an indication for urgent intervention such as an open fracture and/or associated neurovascular injury.
- Closed nailing is not advised when there is an associated radial nerve injury, as the nerve cannot be seen or assessed intraoperatively.
- Antegrade nailing, although feasible, is controversial because of alleged associated postoperative shoulder complaints due to the intracapsular entry point of the nail that occur in some patients.
- Intramedullary elastic nails are only recommended in children and are therefore not described.

Fig 3.4.1-1a–b
a   Preoperative x-ray: segmental humeral shaft fracture.
b   Postoperative x-ray: stabilization with locked intramedullary humeral nail (UHN—unreamed humeral nail); retrograde insertion.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used and how (eg, antegrade or retrograde nailing)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- UHN set
- Reaming instrument set (just in case)
- Hand reamer set
- General orthopaedic instruments
- Compatible air or battery drill
- Attachment for intramedullary reaming (just in case)

Equipment:
- Standard OR table
- Positioning accessories to assist with prone position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

Author   Rogier Simmermacher

3   Anesthesia

■   Due to patient position and working area, only general anes-
    thesia provides adequate comfort for the patient and the op-
    erating team.

4   Patient and x-ray positioning

■   Position the patient either prone or lateral. The prone position
    is described.
■   Place the upper arm on a radiolucent arm board or arm rest,
    with the elbow flexed to 90º (Fig 3.4.1-2).
■   Support the thorax before fixation of the patient's head.
■   Take care to position the head and fix the endotracheal tube
    securely.
■   Introduce the image intensifier from the top of the OR table.
■   The entire humerus including humeral head and elbow must
    be visible in two planes with the image intensifier.
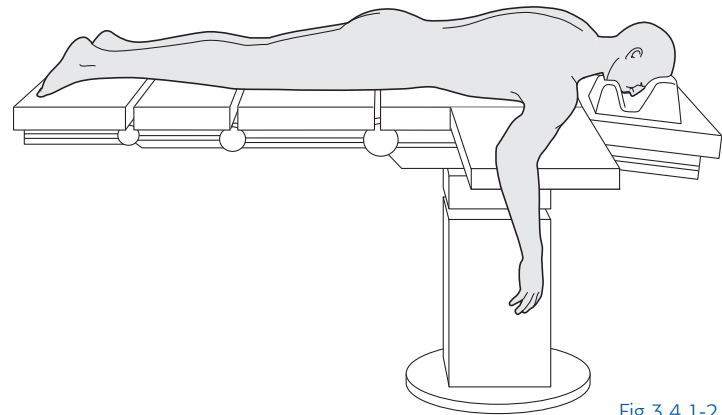
Fig 3.4.1-2

5 Skin disinfecting and draping

- Disinfect exposed area from the neck to the hand including the axilla with the appropriate antiseptic (Fig 3.4.1-3a).
- Drape in such a way as to leave the humeral head area, upper arm, and elbow joint exposed. The hand and forearm should be draped separately with a stockinette well fixed to the forearm (Fig 3.4.1-3b).
- Drape the image intensifier.
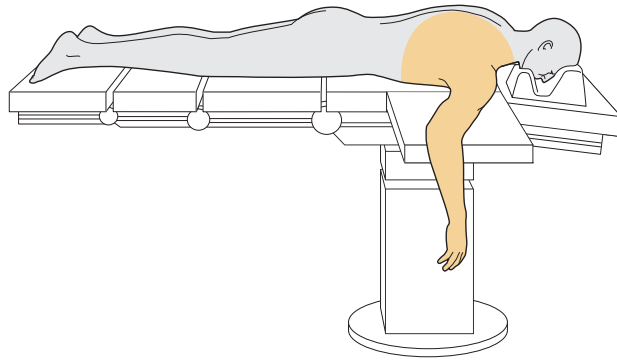
Fig 3.4.1-3a
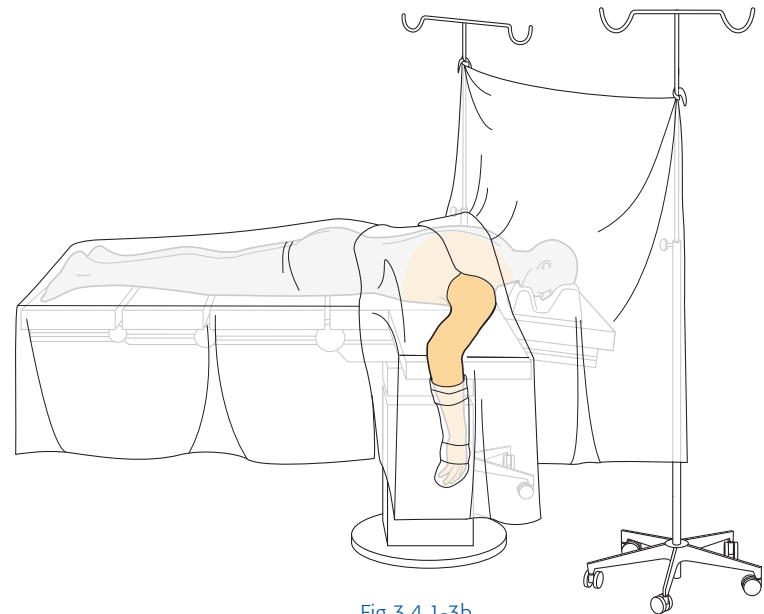
Fig 3.4.1-3b

Author   Rogier Simmermacher

6   Operating room set-up

- The anesthetist and anesthetic equipment should be situated at the side of the patient.
- The surgeon and assistant stand on the side of the injury.
- The ORP stands between (behind) the surgeons.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.4.1-4).
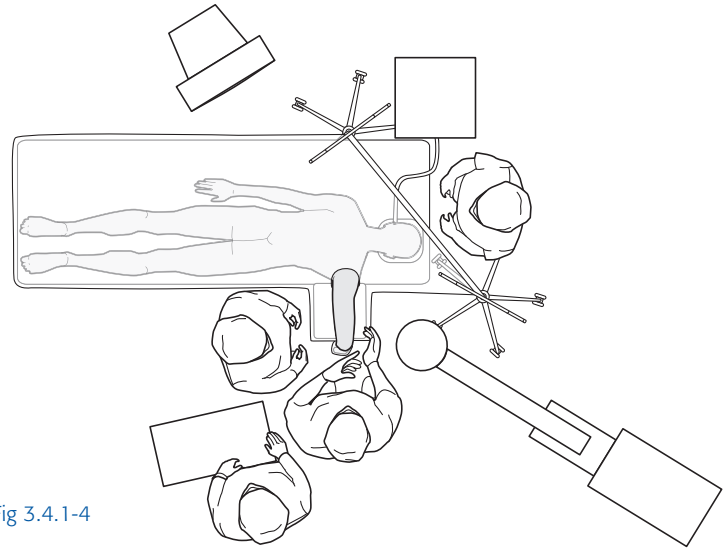
Fig 3.4.1-4

7 Instrumentation
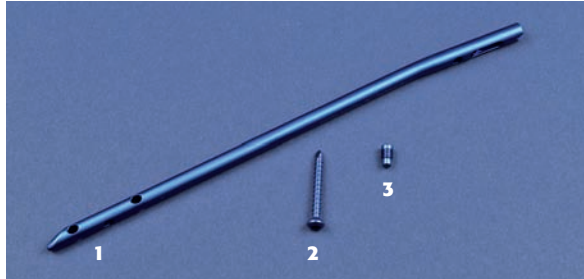
Fig 3.4.1-5a Implants
1. UHN 7.5 mm
2. Locking bolt 3.9 mm
3. End cap
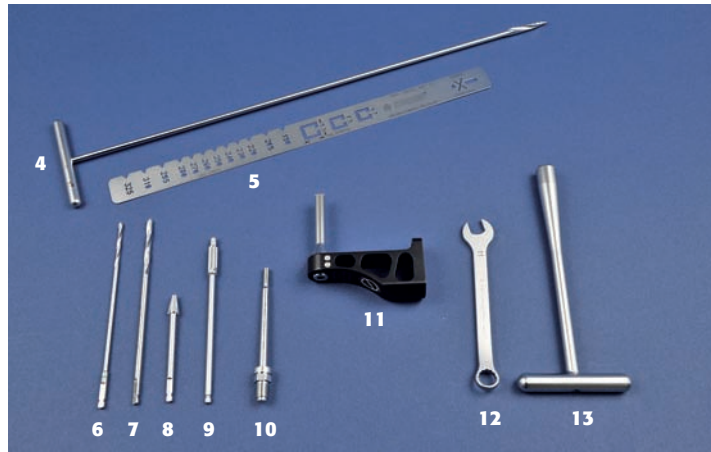
Fig 3.4.1-5b Instruments for opening of medullary canal and nail insertion
4. Hand reamer for medullary canal
5. Radiographic ruler
6. Drill bit 3.2 mm
7. Drill bit 4.5 mm
8. Burr 8.5/3.5 mm
9. Router
10. Connecting screw
11. Insertion handle
12. Combination wrench 11 mm
13. Socket wrench 11 mm

Fig 3.4.1-5c Instruments for proximal and distal locking
14. Aiming arm
15. Double drill sleeve assembly (protection sleeve 11/8.0 mm and trocar 8.0 mm)
16. Drill sleeve 8.0/3.2 mm
17. Drill bit 3.2 mm
18. Depth gauge for locking bolts
19. Screwdriver large for locking bolts and for end cap with extension
20. Screwdriver small for end cap 0 mm
21. Radiolucent drive
22. Drill bit 3.2 mm for radiolucent drive
23. Direct measuring device

Author   Rogier Simmermacher
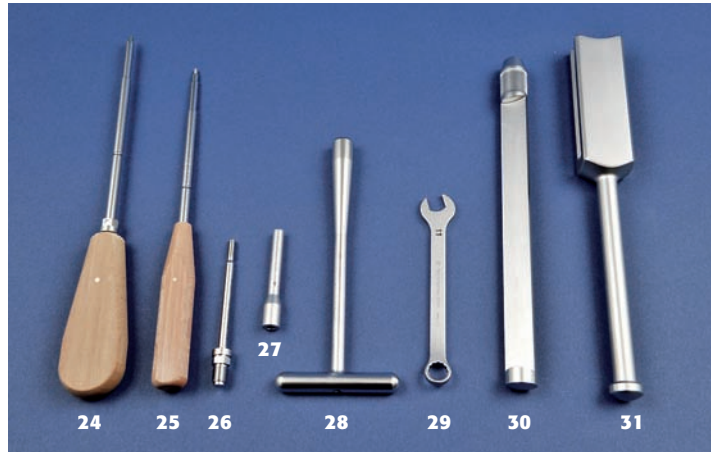
Fig 3.4.1-5d   Instruments for implant removal
24.   Screwdriver large for locking bolts and for end cap with extension
25.   Screwdriver small for end cap 0 mm
26.   Connecting screw
27.   Connecting piece for extraction
28.   Socket wrench 11 mm
29.   Combination wrench 11 mm
30.   Extractor
31.   Slotted hammer

8 Procedure and technique step-by-step

- Make a straight 8–10 cm incision on the posterior aspect of the arm from the tip of the olecranon proximally in the mid-line.
- Split the triceps and expose the triangular surface of the distal humerus just proximal to the olecranon fossa.
- Open the humeral shaft in the center of the triangle by drilling three holes perpendicular to the bone surface, with a 3.2 mm drill bit (Fig 3.4.1-6a).
- Then enlarge these holes using a 4.5 mm drill bit which is gently inclined to about 30º from the long axis of the humerus to meet the medullary canal.
- Use the 8.5 mm conical burr to combine all holes to make a window of about 10 mm width and 20 mm length (Fig 3.4.1-6b).
- If the intramedullary canal is narrow, gently enlarge it with hand reamers.
- Determine the correct nail diameter and length (eg, 7.5 mm

- diameter, length 280 mm) with the radiographic ruler and image intensifier (Fig 3.4.1-6c).
- Assemble the nail and insertion handle with the connecting screw.
- Insert the nail manually by gently rotating it back and forth, passing it across the fracture under the guidance of the image intensifier (Fig 3.4.1-6d).
- Do not hammer the nail in, as this may risk fracturing the bone at the insertion site.
- Advance the nail until its tip protrudes only slightly into the humeral head. This allows a proximal locking bolt to be placed from lateral to medial into the humeral head distal to the rotator cuff.
- Whether to lock distally or proximally first is at the surgeon's discretion.
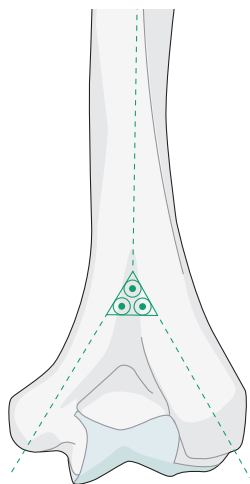
Fig 3.4.1-6a

Fig 3.4.1-6b

Fig 3.4.1-6c

Author   Rogier Simmermacher
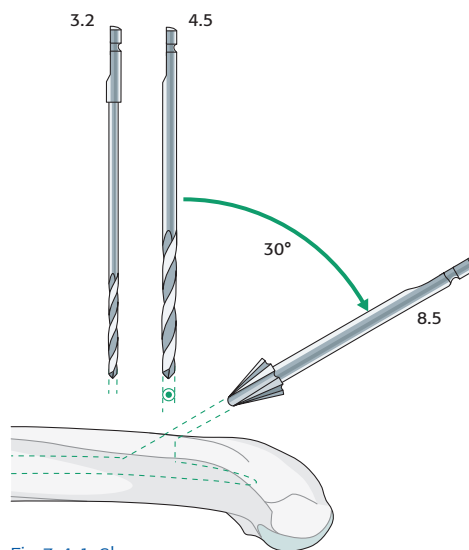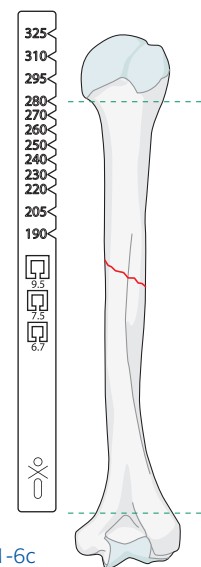
Distal locking

- Mount the aiming arm on the insertion handle, and check that the insertion handle is still firmly attached to the nail by further tightening the connecting bolt.
- Insert the drill sleeve assembly through the aiming arm. Make a stab incision in the skin and push the assembly hard up against the bone (Fig 3.4.1-6e).
- Use the 2.7 or 3.2 mm (depending on nail diameter) drill bit to drill the first locking bolt hole from posterior to anterior.

- Determine the bolt length (direct reading from calibrated drill bit just before perforating the far cortex) and add 2 mm to fully engage the bolt in the opposite cortex.
- Insert an appropriate length 3.4 or 3.9 mm self-tapping locking bolt with the screwdriver through the protection sleeve.
- Repeat the sequence for the second locking bolt insertion.
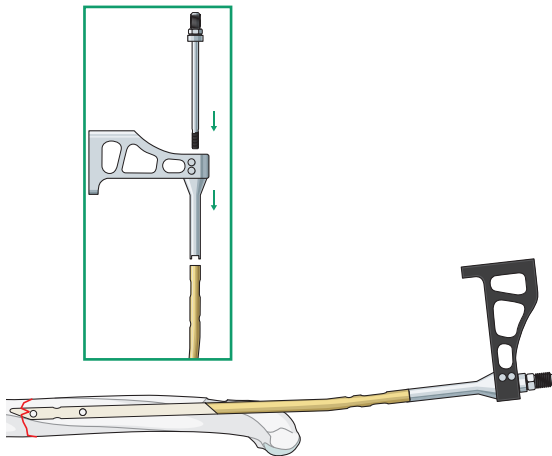
Fig 3.4.1-6d
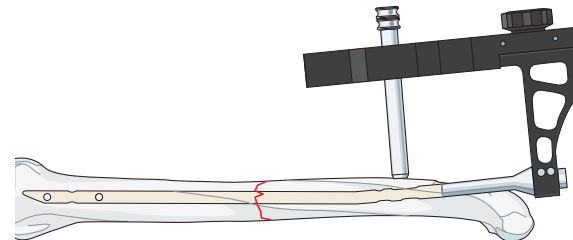
Fig 3.4.1-6e

Proximal locking

- Check the fracture reduction with the image intensifier (there must be no gap) and double check the rotation clinically.
- Proximal locking is done lateral to medial and may be performed freehand or using a radiolucent drive.
- Align the C-arm with the hole in the nail until a perfect circle is visible on the screen (Fig 3.4.1-6f–g).
- Place a scalpel blade on the skin over the center of the hole to mark the incision point and make a stab incision in the skin. Do not use the scalpel to deepen the incision as this could damage the axillary nerve.
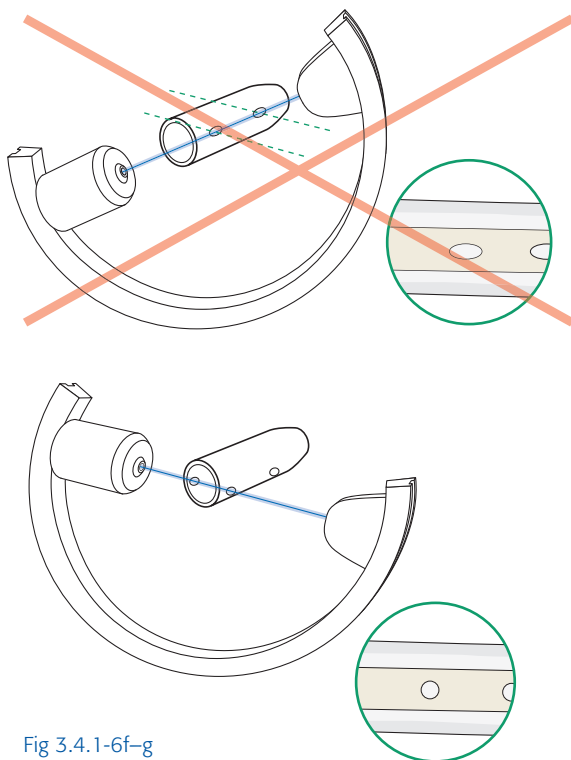
- Dissect down to the bone using a blunt instrument.
- Position the tip of a 3.2 or 2.7 mm (depending on nail diameter) sharp drill bit obliquely through the incision. Under the guidance of the image intensifier place the tip of the drill bit over the center of the hole and hold it there firmly (Fig 3.4.1-6h).
- Ensure that the drill bit tip does not move on the bone. Change the angle of the drill bit until it is exactly aligned with the axis of the image intensifier beam.
- Using a radiolucent drive allows continuous checking of the position of the drill bit over the hole in the nail while drilling.

Fig 3.4.1-6f–g

Fig 3.4.1-6h

Author   Rogier Simmermacher
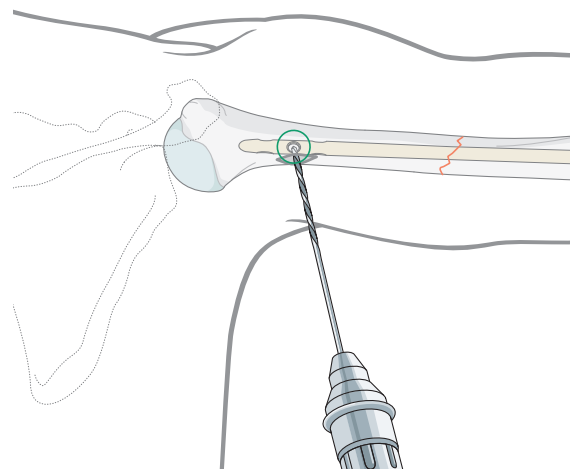
- Now drill—without slipping on the bone surface—the hole of the first cortex. Stop drilling and manually guide the drill bit through the hole in the nail before drilling the far cortex (Fig 3.4.1-6i).
- Because the drill bit frequently slips on the bone surface during drilling many surgeons indent the bone overlying the center of the hole in the nail using a short Steinmann pin and a hammer.
- Use the image intensifier to verify that the drill bit lies within the hole of the nail.

- Measure the bolt length using the depth gauge. Ensure that the outer sleeve is in contact with the bone and the hook grasps the far cortex. Add 2 mm.
- Insert the appropriate length 3.4 or 3.9 mm locking bolt using the screwdriver.
- Use the image intensifier to verify the screw length.
- A second proximal locking bolt may be inserted using the same technique (Fig 3.4.1-6j).
- Select and insert the appropriate end cap for the nail.
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 20165: The Unreamed Humeral Nail (UHN).
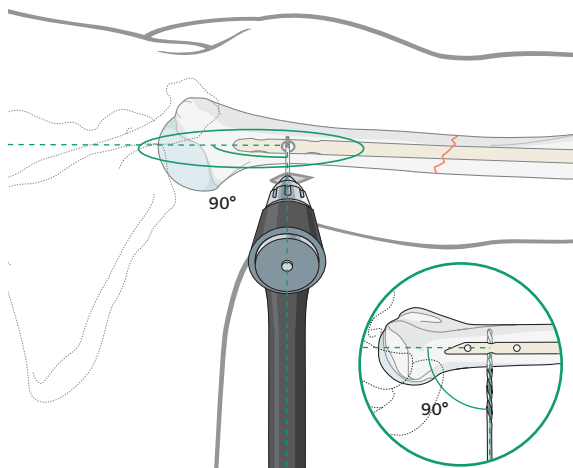
Fig 3.4.1-6i
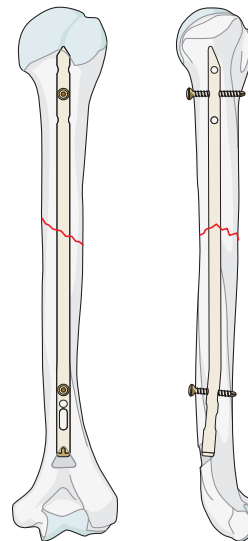
Fig 3.4.1-6j

9 Specific perioperative care

- Confirm that the patient is appropriately positioned and secured on the operating table.
- Check that pressure points are well padded.
- Maintain sterility of the surgical field when the flexed arm is moved and image intensification is used.

10 Specific postoperative care

- Gradually increase the range of motion of the elbow and shoulder from postoperative day 1 onward.
- Avoid rotational movements against resistance until bridging callus is visible on x-ray.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of instruments and implants are available.

- Check that hand reamers are available.
- Do not confuse different sizes of nails, drill bits, and bolts.
- Document and reorder all implants used.

12 Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Make sure the function of the radial nerve is checked and documented before and after surgery.
- Check that the image intensifier can rotate to obtain suitable views before scrubbing and draping.
- Take great care to make a large enough opening window proximal to the olecranon fossa to prevent any cracks or iatrogenic fracture during nail insertion.

- Insert the nail by hand; do not hit it with a hammer.
- Make sure the axillary nerve is not damaged during proximal locking by dissecting carefully down to bone using blunt dissection.
- There should be no residual gap at the fracture site.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author Rogier Simmermacher

3.4.2 Humeral shaft fracture (12-A1): stabilization with LC-DCP 4.5 narrow

Surgical management

- Stabilization with LC-DCP 4.5 narrow

Alternative implants

- Intramedullary humeral nail UHN (antegrade or retrograde)
- Plating with:
  - LCP 4.5/5.0 narrow or broad (open or using a MIPO technique)
  - DCP 4.5 broad or narrow

1 Introduction

- Most closed humeral shaft fractures are treated nonoperatively by bracing or splinting. Indications for surgery must be carefully evaluated.
- Perform surgery within 8–10 days after injury, unless there is an indication for urgent intervention such as an open fracture and/or associated neurovascular injury.
- Plating is particularly indicated when exploration of the radial nerve is required or if there is distal or proximal fracture extension.
- Simple oblique (and transverse) fractures are best treated using plates and interfragmentary compression to provide absolute stability.

Fig 3.4.2-1a–b
a   Preoperative x-ray: spiral humeral shaft fracture.
b   Postoperative x-ray: stabilization with a lag screw and LC–DCP 4.5 narrow placed on anterior surface of the humerus.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Large fragment set
- LC-DCP 4.5 narrow plate set
- LC-DCP 4.5 broad plate set (just in case)
- Bending tools
- Vessel loops for radial nerve exploration
- General orthopaedic instruments
- Compatible air or battery drill

Equipment:
- Standard OR table with radiolucent side table or arm rest
- Positioning accessories to assist with prone position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

Author   Rogier Simmermacher

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Prone position of the patient for a posterior approach to the humerus (Fig 3.4.2-2).
- The alternative beach chair position for an anterior approach is not described, but is illustrated in chapter 3.3.
- The upper arm is placed on a radiolucent table extension with the elbow flexed.
- The image intensifier is introduced from the top of the OR table. The entire humerus including humeral head and elbow must be visible in two planes with image intensification.
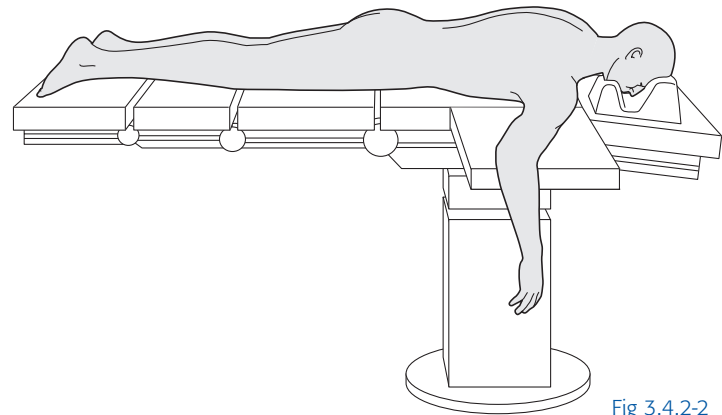
Fig 3.4.2-2

5 Skin disinfecting and draping

- Disinfect the exposed area from the neck to the hand, including the axilla, with the appropriate antiseptic (Fig 3.4.2-3a).
- Drape in such a way as to leave the posterior aspect of the arm exposed from shoulder to elbow. Drape the hand and forearm

separately with a stockinette fixed properly to the forearm (Fig 3.4.2-3b).
- Drape the image intensifier.

Fig 3.4.2-3a

Fig 3.4.2-3b

Author   Rogier Simmermacher
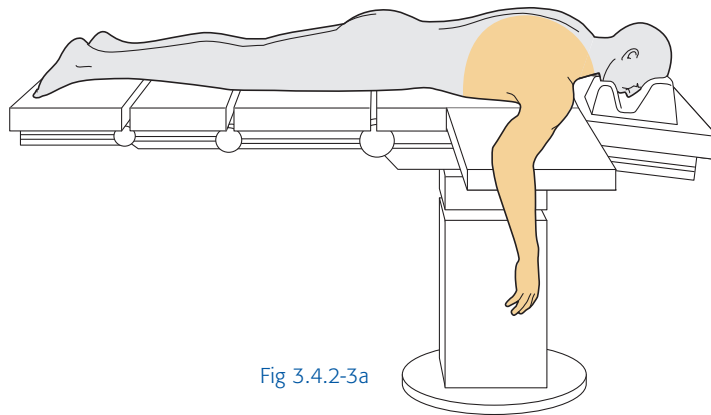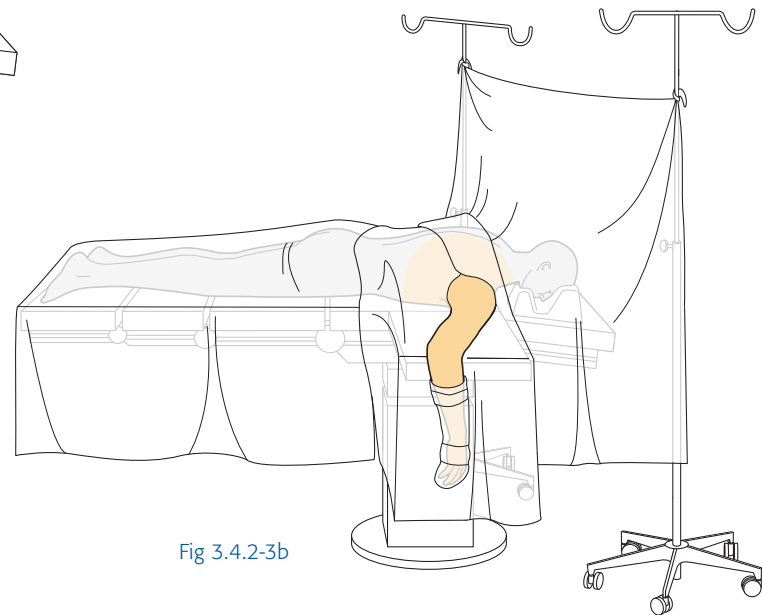
6   Operating room set-up

- The anesthetist and anesthetic equipment are situated to the side of the patient.
- The surgeon and assistant stand on the side of the injury.
- The ORP stands between (behind) the surgeons.
- When required, the image intensifier is introduced from the top of the OR table.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.4.2-4).
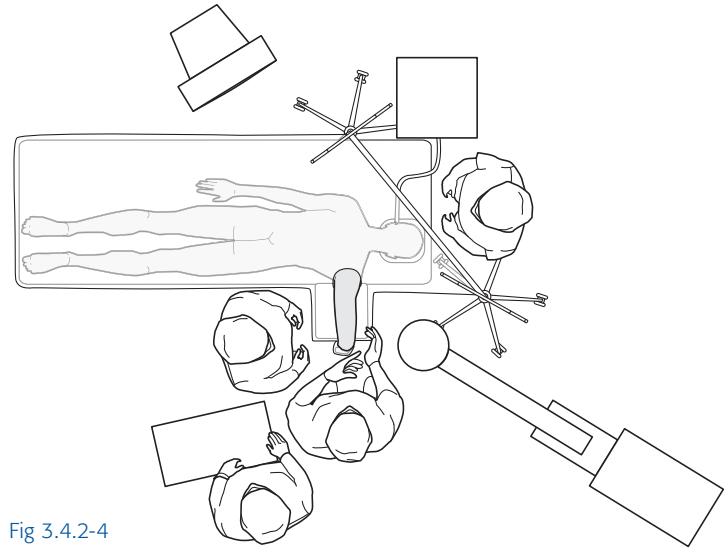
Fig 3.4.2-4

7 Instrumentation
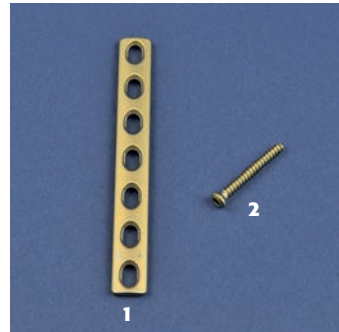
Fig 3.4.2-5a   Implants
1. LC-DCP 4.5 narrow mm
2. Cortex screw 4.5 mm
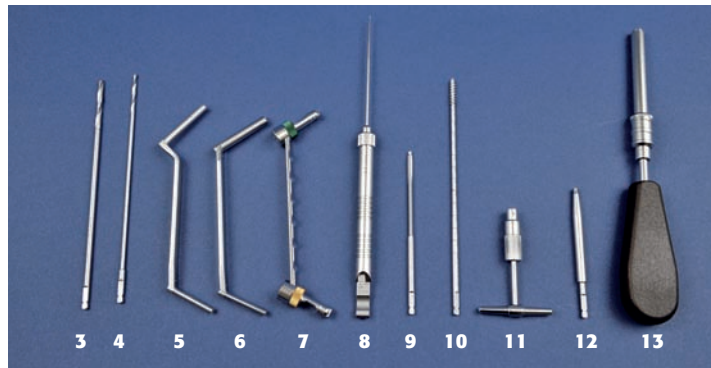
Fig 3.4.2-5b   Instruments for fracture fixation with LC-DCP 4.5 narrow
3. Drill bit 4.5 mm
4. Drill bit 3.2 mm
5. Double drill sleeve 4.5/3.2 mm
6. Double drill sleeve 6.5/3.2 mm
7. LC-DCP drill sleeve 4.5 mm
8. Depth gauge
9. Tap 4.5 mm
10. Tap 6.5 mm
11. T-handle
12. Screwdriver shaft
13. Screwdriver with holding sleeve

Fig 3.4.2-5c   Instruments for reduction and contouring
14. Bending press
15. Reduction forceps with points, large
16. Bending iron (two)

Author   Rogier Simmermacher

8   Procedure and technique—step-by-step

- The dorsal approach, with the patient in prone position and the elbow flexed.
- Make a 10–15 cm midline longitudinal incision overlying the posterior aspect of the arm. The exact length and positioning of the incision depends on the site of the fracture and the size of plate to be used. Split the triceps muscle between the lateral and the long head of the muscle. Identify the radial nerve and accompanying vessels and protect them with a vessel loop as they cross the humerus.

- Make sure that the radial nerve is mobile enough to slide the plate beneath it.
- The exact fixation method should be planned preoperatively and depends on the fracture configuration. Here we describe applying the plate as a compression plate.
- Reduce the fracture directly using two pointed reduction forceps (Fig 3.4.2-6a).
- Select a narrow LC-DCP 4.5 mm of appropriate length (at least 9 holes), contour it, and prebend it to maximize compression (Fig 3.4.2-6b).
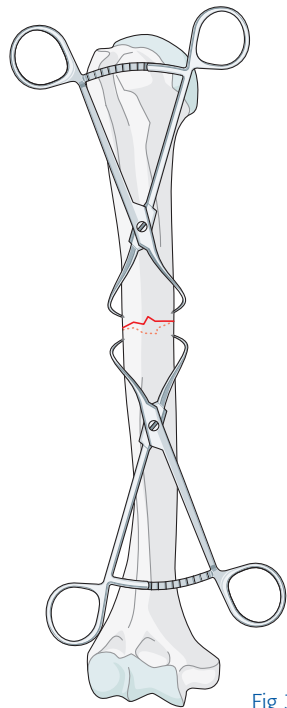
Fig 3.4.2-6a
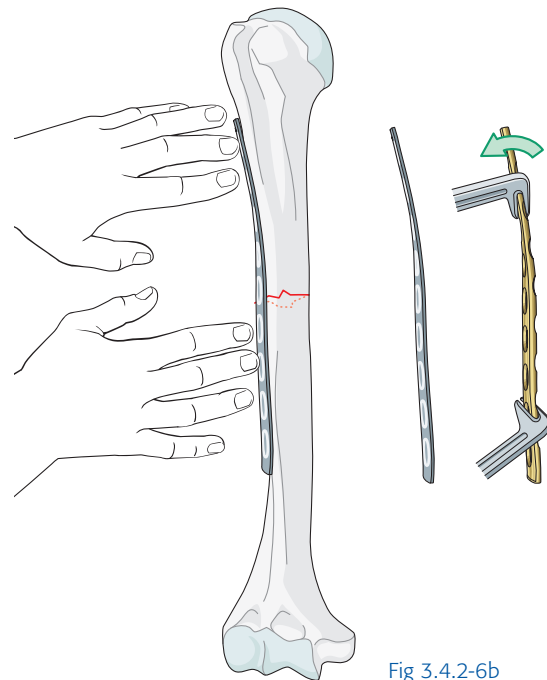
Fig 3.4.2-6b

- The first screw must be placed through the plate in neutral position, fixing the plate to the bone.
- Drill the first hole using the 3.2 mm drill bit and the LC-DCP drill sleeve with the green end. This ensures that the screw will be inserted in a neutral position. Determine that the arrow on the green sleeve points toward the fracture.
- Measure the screw length and tap with the 4.5 mm cortical tap and corresponding sleeve. Insert the appropriate length 4.5 mm cortex screw.
- Ensure the fracture is accurately reduced.
- In the other fracture fragment, place the yellow LC-DCP drill sleeve in the plate hole closest to the fracture with the arrow pointing toward the fracture and drill an eccentric hole with the 3.2 mm drill bit.
- Measure, tap, and insert the screw. As the screw is tightened, interfragmentary compression is obtained (Fig 3.4.2-6c).
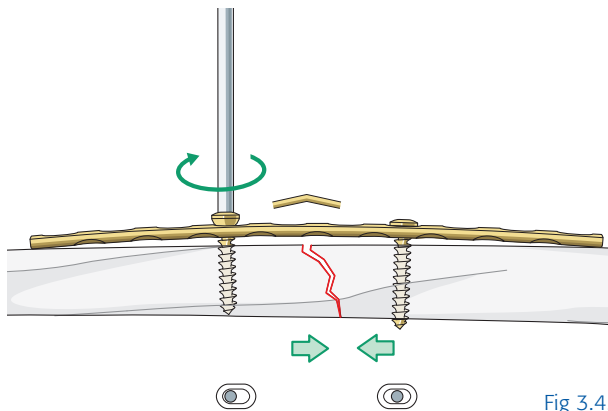
- Insert further neutral screws, using the green 3.2 mm drill guide through the plate. It is recommended that a total of eight cortices (four screws) are secured on each side of the fracture.
- Insert the cortex screws in a slightly off-set pattern so that the tips are not in line in the opposite cortex which may cause a stress riser.
- Make a note in the OR report of the radial nerve position relative to the plate holes (Fig 3.4.2-6d).
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 30126: Humerus, mid-shaft—short oblique fracture fixation with an independent lag screw and the LC-DCP used as a neutralization plate.

Fig 3.4.2-6c

Fig 3.4.2-6d

Author   Rogier Simmermacher
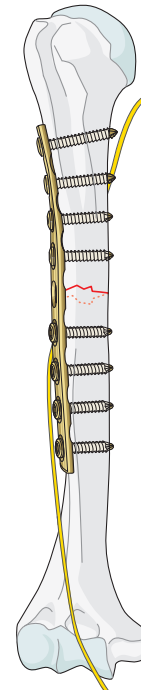
9   Specific perioperative care

- Confirm that the patient is well positioned and secured on the operating table.
- Check that pressure points are well padded.
- Maintain sterility of the surgical field when the hanging arm is moved and intensification used.

10   Specific postoperative care

- Position the arm slightly abducted on a cushion.
- Immediately start controlled active mobilization of the shoulder and elbow.
- Delay exercises with rotation of the humerus until the second postoperative week.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of instruments and implants are available.
- Remember vessel loops for radial nerve identification and protection.

- Distinguish between insertion of compression screws and neutral screws.
- Use LC-DCP drill sleeve correctly.
- Document and reorder all implants used.

12   Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Detailed preoperative planning is essential.
- Be sure the radial nerve function has been checked and documented before and after surgery.
- Take great care of the radial nerve and note in the OR report at what level it crosses the plate.

- Check that unobstructed image intensification of entire humerus in both planes is possible before draping.
- Open direct reduction requires a fixation, which provides absolute stability (minimum 8-hole plate).
- In a large patient it may be desirable to apply a broad rather than a narrow plate.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.5 Distal humeral fractures

Author   Bruce Twaddle

3.5   Distal humeral fractures
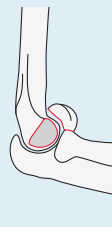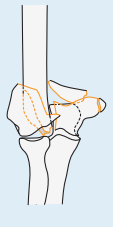
Case

- Type 13-C1 fracture, stabilized with lag screws and reconstruction plate

---

Introduction

- The Müller AO/OTA Classification divides distal humeral fractures into three groups:
  - type 13-A: extraarticular fractures of the distal humeral metaphysis
  - type 13-B: partial articular fractures of the distal humerus
  - type 13-C: complete articular fractures of the distal humerus
- Fractures of the distal humerus occur in all age groups, but tend to have a bimodal incidence occurring in high-velocity injuries in young adults, usually males; and in relatively osteoporotic bone with low-velocity injuries, usually in elderly women.
- Isolated, undisplaced fractures of the distal humerus can be treated nonoperatively with splintage and carefully supervised mobilization.
- Extraarticular fractures of the distal humerus are common in pediatric patients, but are not covered in this chapter.
- Complete articular fractures of the distal humerus are relatively uncommon and are surgically challenging fractures.
- Surgery is always indicated unless the patient is not fit enough for anesthesia.

- The surface anatomy of the distal humerus is complex, can be difficult to reconstruct, and always requires a good view of the joint surface.
- The fractures have a short distal or "joint block" segment which requires anatomical reconstruction. This block has to be accurately and firmly fixed to the humeral shaft with plates to allow early mobilization of the elbow.
- Detailed planning of distal humeral fracture reconstruction is mandatory.
- The most common exposure is through a posterior approach mobilizing the distal triceps. This may be combined with an olecranon osteotomy (usually chevron shaped) of the proximal part of the olecranon and its triceps attachment. The olecranon requires fixation back in place at the end of the procedure.
- The key to accurate surgical reconstruction is using K-wires to provide provisional reduction and stabilization of the joint segment, then alignment of this segment with the rest of the humerus. Details of the K-wire placement forms part of the surgical tactic.

Müller AO/OTA Classification—distal humerus

| 13-A1 | 13-A2 | 13-A3 | 13-B1 | 13-B2 | 13-B3 | 13-C1 | 13-C2 | 13-C3 |

13-A   **extraarticular fracture**
13-A1   apophyseal avulsion
13-A2   metaphyseal simple
13-A3   metaphyseal multifragmentary

13-B   **partial articular fracture**
13-B1   sagittal lateral condyle
13-B2   sagittal medial condyle
13-B3   coronal

13-C   **complete articular fracture**
13-C1   articular simple, metaphyseal simple
13-C2   articular simple, metaphyseal multifragmentary
13-C3   articular multifragmentary

3.5.1   Intraarticular distal humeral fracture (13–C2): stabilization with 4.0 mm cancellous bone screws and two reconstruction plates 3.5

Surgical management

- Stabilization with:
  - 4.0 mm cancellous bone screws as lag screws
  - Two reconstruction plates 3.5

Alternative implants

- LCP reconstruction plates 3.5
- Distal humeral contoured locking plates 3.5/2.7

1   Introduction

Fig 3.5-1a–b
a   Preoperative x-ray: displaced complete articular distal humeral fracture.
b   Postoperative x-ray: stabilization with lag screws and two reconstruction plates 3.5. Note, a tension band wiring is used to fix olecranon osteotomy.
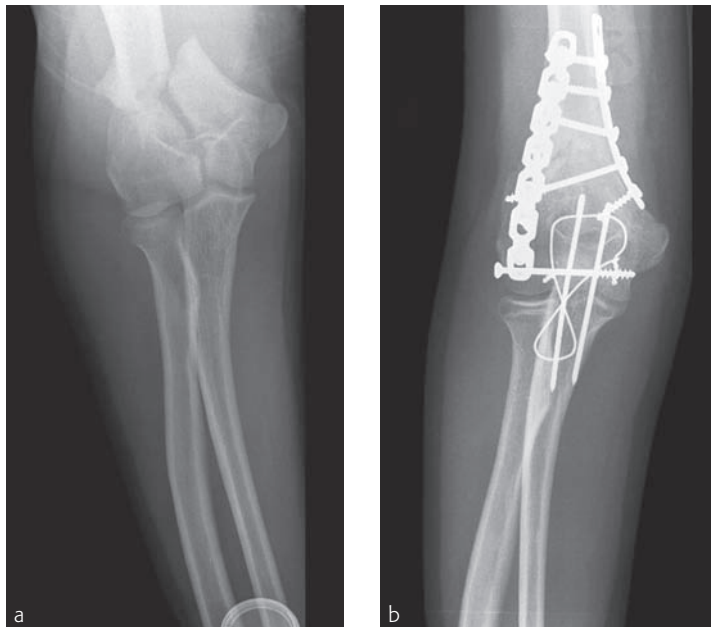
- There is debate about the exact placement of plates when fixing these fractures. A posterior plate on the lateral side combined with a medial plate at 90° is described. A combined posteromedial and posterolateral plate configuration is used by some surgeons.
- The use of a locked screw fixation and precontoured implants are both techniques that improve mechanical support. These options are described.
- Occasionally bone grafting is necessary and should be considered before preparation of the patient to allow draping of the donor site, if required.
- Nonunion of these fractures is rare and usually occurs early because of inadequate mechanical support from the implants selected.
- Caution the patient that even with excellent anatomical reduction, some loss of motion can be expected.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed)
- Implants to be used (care: different plates may be used)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instrument and screw set 3.5 mm
- Reconstruction plate 3.5 set
- Bending tools
- Tension band wiring set
- K-wire selection 1.4–2.0 mm
- Bone graft set
- Vessel loops
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Oscillating saw for olecranon osteotomy

Equipment required:
- Radiolucent operating table
- Positioning accessories to assist with prone or lateral position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3 Anesthesia

- This procedure is performed with the patient under general anesthesia.
- While technically possible, regional anesthesia is not advised as the procedure can be prolonged.

Author   Bruce Twaddle

4   Patient and x-ray positioning

- With the patient anesthetized, positioning should allow the arm and the elbow free to be straightened and bent to at least a right angle.
- This can be achieved either with the patient prone or in the lateral position.

Prone position
- Place the patient prone as far toward the same side of the table as possible.
- Position the arm over a bolster or custom-made support with appropriate padding so that the elbow movement is free (Fig 3.5-2a).
- Secure the patient's body with padded side supports.
- Ensure that the shoulder is not too extended so there is no tension on the brachial plexus.

Lateral position
- Secure the patient's body with padded side supports (Fig 3.5-2b).
- Abduct the operated arm across the body with the shoulder at 90º, and over a custom-made support or bolster with appropriate padding (Fig 3.5-2c).

- To allow adequate access for imaging, position the patient as far as possible toward the side of the table from which the arm will be accessed.
- Always ensure the anesthetist is satisfied with the position and support of the patient's face and has adequate access to the airway at all times.
- Take great care with the soft tissue and skin pressure points, particularly in the elderly.
- Autogenous bone grafting is a possibility and access to an iliac crest or to another bone graft harvest site will be required.
- Imaging can be performed with plain films or with the use of the image intensifier. Plain films are more appropriate if it is difficult to obtain adequate access with the image intensifier.
- Ensure there is adequate access for imaging before disinfecting and draping.
- If a tourniquet (sterile or nonsterile) is to be used, make sure the cuff is narrow enough that it will not encroach on the surgical field required for exposure.
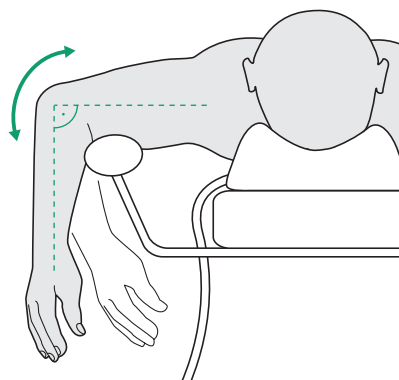
Fig 3.5-2a
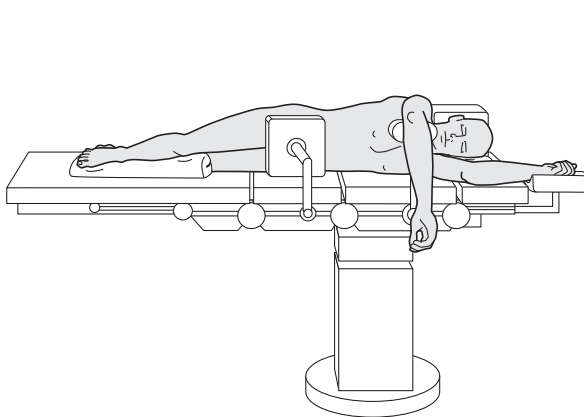
Fig 3.5-2b
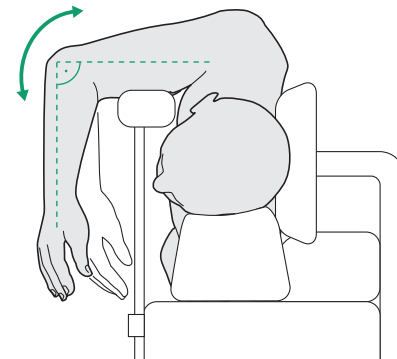
Fig 3.5-2c

5 Skin disinfecting and draping

- During disinfecting and draping make sure the shoulder is not too extended, particularly in elderly patients. It is often useful to elevate the table for this part of the preparation to make it easier for the assistant and then adjust the height to suit the surgeon.
- Disinfect the exposed area from the shoulder to the hand including the axilla with the appropriate antiseptic (Fig 3.5-3a). Adapt area to be disinfected if unsterile tourniquet has been applied.
- Disinfect the iliac crest for harvesting of a bone graft. It is best practice to always prepare a site for bone graft harvesting even if it turns out not to be required.

- Apply an extremity drape to the affected arm making sure that sufficient coverage is achieved to access the surgical field (Fig 3.5-3b). Drape the distal forearm with a stockinette and fix it with a tape.
- Drape the bone graft site separately.
- Drape the image intensifier.
- Different imaging positions are usually achieved by rotating the patient's arm, but at times it is necessary to rotate the image intensifier.

Fig 3.5-3a

Fig 3.5-3b

Author   Bruce Twaddle
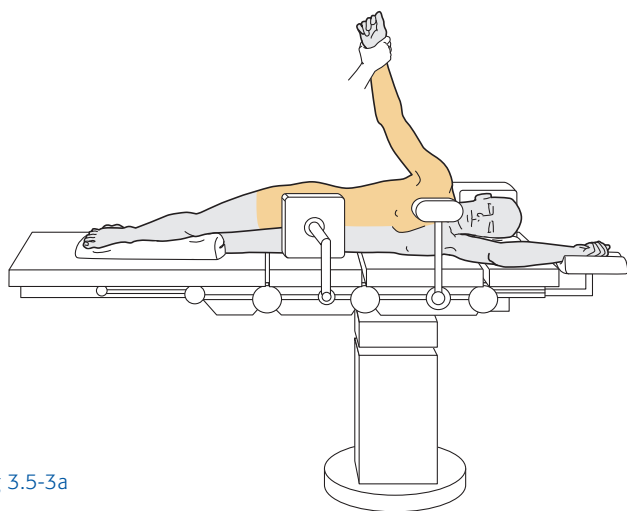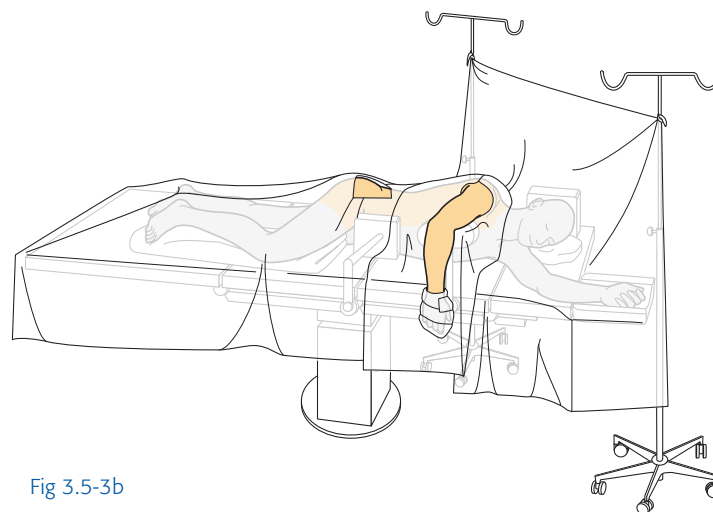
6   Operating room set-up

- The surgeon sits or stands adjacent to the patient's axilla.
- The assistant sits or stands opposite the surgeon. They may need to move to allow the image intensifier access.
- The ORP is positioned directly in line with the arm between the two surgeons.
- The image intensifier is brought in from the head of the table.
- It is possible on some pedestal radiolucent tables to bring the image intensifier in from the opposite side of the table so it interferes less with the surgical field.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.5-4).
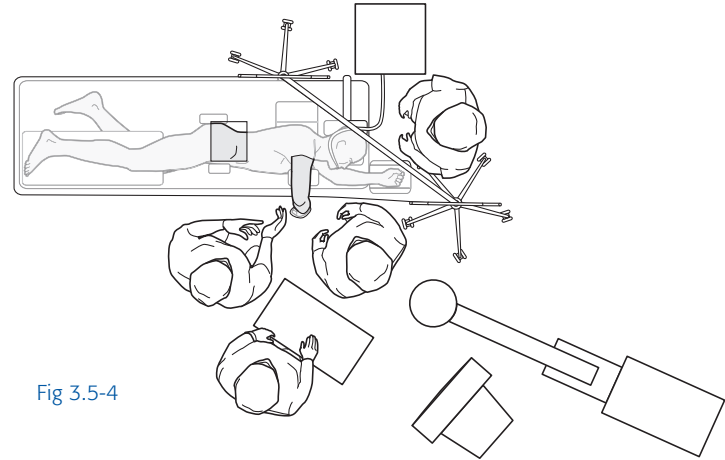

Fig 3.5-4

7 Instrumentation
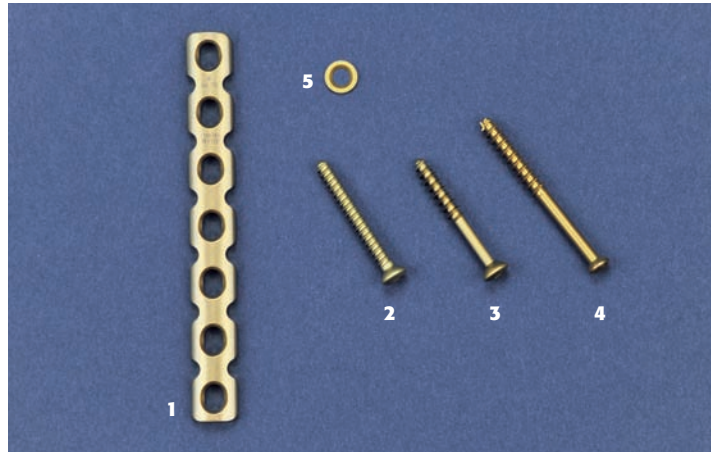
Fig 3.5-5a   Implants
1. Reconstruction plate 3.5, 7 holes
2. Cortex screw 3.5 mm
3. Cancellous bone screw 4.0 mm, partially threaded
4. Cannulated cancellous bone screw 4.0 mm, partially threaded
5. Washer
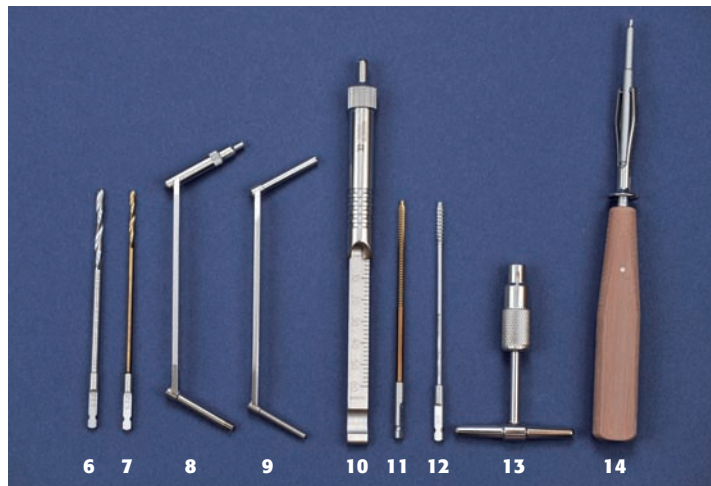
Fig 3.5-5b Instruments for fracture fixation with reconstruction plate 3.5
6. Drill bit 3.5 mm
7. Drill bit 2.5 mm
8. Universal drill sleeve 3.5 mm
9. Double drill sleeve 3.5/2.5 mm
10. Depth gauge
11. Tap 3.5 mm for cortex screw
12. Tap 4.0 mm for cancellous bone screw
13. T-handle
14. Screwdriver with holding sleeve

Author Bruce Twaddle
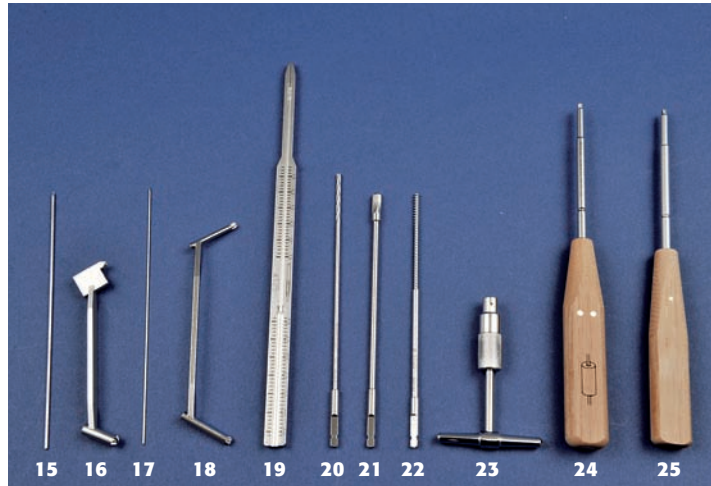
Fig 3.5-5c Instruments for fracture fixation with cannulated 4.0 mm cancellous bone screws
15. K-wire 1.6 mm (for preliminary fixation)
16. Triple drill guide 2.0 mm
17. K-wire 1.25 mm, 150 mm
18. Double drill sleeve 2.7/1.25 mm
19. Direct measuring device
20. Cannulated drill bit 2.7 mm
21. Cannulated countersink 4.0 mm
22. Cannulated tap 4.0 mm for cannulated cancellous bone screw
23. T-handle
24. Cannulated screwdriver
25. Screwdriver (standard)
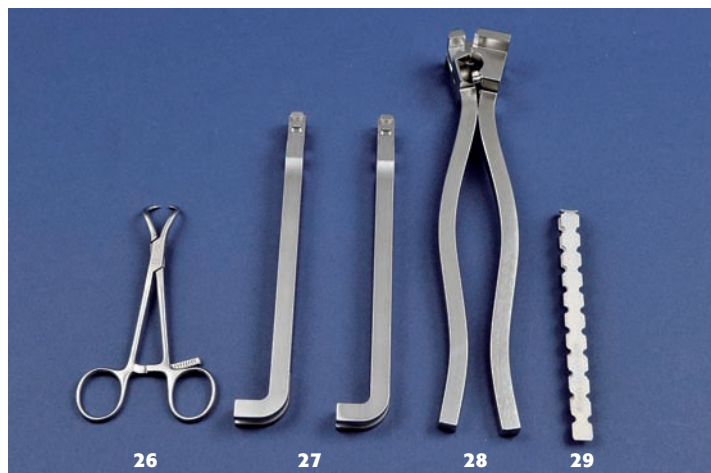
Fig 3.5-5d Instruments for reduction and contouring
26. Reduction forceps with points, medium
27. Bending iron for reconstruction plates 3.5 (two)
28. Bending pliers for reconstruction plates 3.5
29. Bending template for reconstruction plates 3.5

8 Procedure and technique—step-by-step

- Incision: make a midline on the posterior surface of the elbow. Proximally the incision follows the line of the humerus. Curving the incision at the elbow avoids having a scar on the point of the olecranon.
- Identify the ulna nerve and protect it with a vascular loop. In some cases if the nerve is in the way of reduction or interferes with fixation and the final position of the plate, it can be transposed in front of the medial epicondyle at the end of the procedure.
- Mobilize the triceps mechanism medially and laterally. It may be necessary to separate it from the ulna distally as a subperiosteal flap, or free it attached to a proximal piece of the olecranon after a controlled "chevron" osteotomy.
- If an osteotomy is required, start with an oscillating saw and complete the last few millimeters with an osteotome to minimize damage to the articular surface of the olecranon (Fig 3.5-6a).
- Identify the intraarticular fracture fragments and reduce the joint as anatomically possible using appropriately sized reduction clamps and temporary K-wires (Fig 3.5-6b).
- Bone grafting may now be required if a structural part of the articular segment is missing.

- Achieve definitive fixation of the joint segment with one or two 4.0 mm cancellous bone screws, depending on the size of the articular block.
- Drill a 2.5 mm hole across both fragments from lateral to medial, parallel to the joint surface. Measure the screw length and tap with the 4.0 mm (silver) tap.
- Insert the appropriate partially threaded cancellous bone screw, ensuring that the threaded portion passes beyond the fracture. As the screw is tightened the fracture site is compressed (Fig 3.5-6c).

Fig 3.5-6a

Fig 3.5-6b

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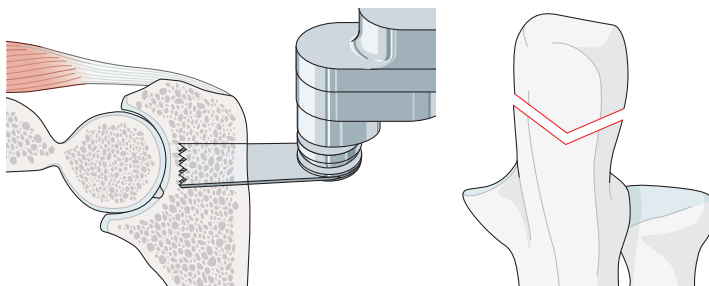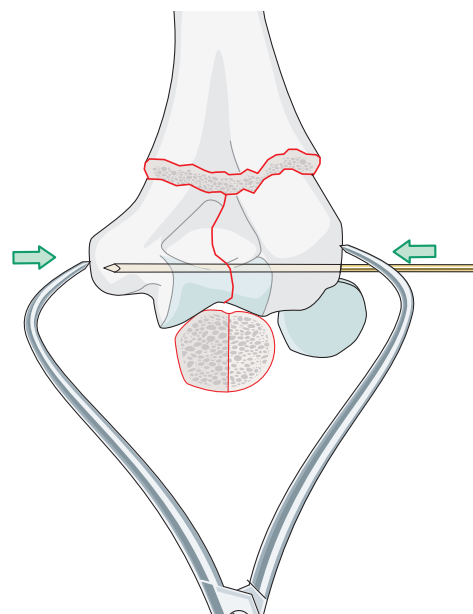
- Partially threaded 4.0 mm cannulated screws or 3.5 mm cortex screws (inserted as lag screws) can also be used depending on the surgeon's preference and the fracture pattern.
- If the articular segment is in more than two pieces the compression produced by a lag screw may displace the reduction. Instead a fully threaded 4.0 mm cancellous bone screw is used as a position screw.
- Drill a 2.5 mm hole, measure the length, and tap with the 4.0 mm (silver) tap.
- Insert the appropriate fully threaded 4.0 mm cancellous bone screw. No compression is exerted as the screw is tightened. A second screw may be added if space allows.

- The stabilized joint segment is provisionally reduced and held to the distal humerus with reduction forceps and K-wires (Fig 3.5-6d).
- Check with the image intensifier the accuracy of the provisional reduction. Be sure that there is no screw penetration into the joint from the articular segment reduction and fixation before proceeding.
- Contour two 5-hole to 6-hole LC-DCP reconstruction plates 3.5 using the corresponding bending templates and pliers to the posterolateral and medial side of the humerus. The exact plate length and position is noted in the preoperative plan (Fig 3.5-6e).
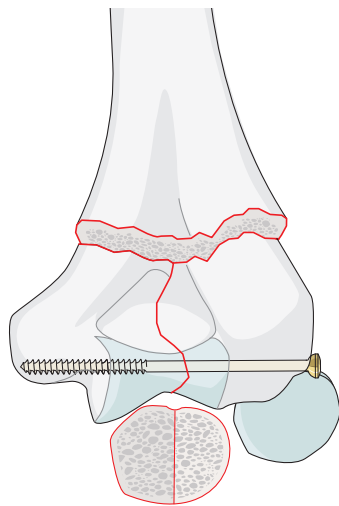
Fig 3.5-6c
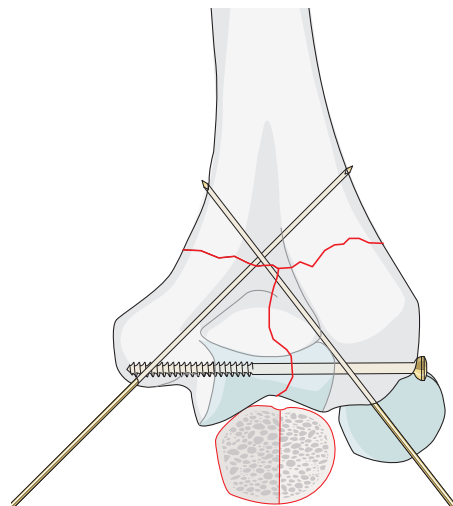
Fig 3.5-6d
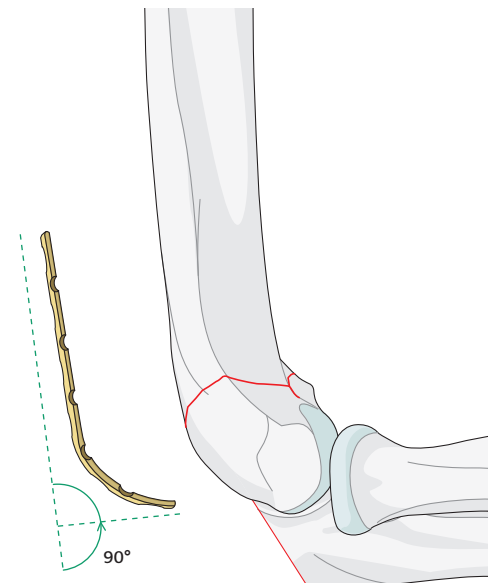
Fig 3.5-6e

- Due to the anatomy of the articular surface of the distal humerus, it is possible to take the posterolateral plate more distally and have more screws placed in the articular segment.
- Seat the medial plate down to the medial epicondyle with screws placed obliquely into the articular segment.
- Make sure the position of the plates does not restrict the elbow range of movement.
- The plate fixation can be complicated by the screws running into either the provisional K-wire fixation or the screws from the other plate. Several adjustments may need to be made to achieve ideal fixation. These problems can be anticipated and often solved by adequate preoperative planning.
- Distally the plates are held by 4.0 mm cancellous bone screws, usually fully threaded. If so, drill the hole with a 2.5 mm drill bit, measure the length, tap with a (silver) 4 mm tap, and insert the required screw. Occasionally a partially threaded screw may be used as a lag screw to compress two fracture fragments.
- Do not penetrate the joint surface with any screws, particularly those in the distal end of the posterolateral plate.
- More proximal screws placed in the humeral diaphysis should be 3.5 mm cortex screws.
- Drill a 2.5 mm hole using the drill sleeve 3.5 mm centered in the plate hole to achieve neutral position. Measure the depth, tap with the 3.5 mm (yellow) tap, and insert the correct length 3.5 mm cortex screw.
- Screw placement and position can usually be controlled under direct vision. Occasionally the image intensifier is required particularly in highly comminuted fractures when screw interference can risk displacing a reduction.
- Once both plates have been inserted, final imaging with x-rays or the image intensifier must be performed and copies saved (Fig 3.5-6f).

- If an olecranon osteotomy has been performed, use the tension band wiring technique for refixation. This procedure is described in chapter 3.6 (Fig 3.5-6g).
- Close the wound.

Alternative implants
- LCP 3.5/ LCP 3.5 reconstruction plates
- Distal humeral contoured locking plates 3.5/2.7

Key differences
- Locking head screws provide much stronger fixation to bone particularly when used to fix small segments of bone or when the bone quality is poor. This makes them particularly appropriate for use in complex elbow fractures, especially in elderly patients.

LCP 3.5 reconstruction plates:
- The conventional reconstruction plate 3.5 can be replaced by the LCP 3.5 reconstruction plate with combination holes (Fig 3.5-7).
- The LCP 3.5 always requires the use of the 2.5 mm universal spring-loaded drill guide for predrilling conventional cortex or cancellous bone screws in the nonthreaded portion of the combination holes.
- For insertion of a locking head screw the threaded drill guide using a 2.8 mm drill bit is used. The locking head screw is inserted in the threaded portion of the combination hole.

Distal humeral contoured locking plates 3.5/2.7:
- The distal humeral contoured locking plates are precontoured to the anatomical shape of the distal humerus and designed to be positioned at right angles to each other. There is a postero-lateral and a medial plate which have limited maneuverability as to where they can be placed (Fig 3.5-8).

Author   Bruce Twaddle

- These locking plates have regular 3.5 combination holes proximally but clusters for 2.7 mm locking head screws distally that are orientated at predetermined angles.
- When positioning the posterolateral plate the exact height of the plate is critical. If placed too distal, the 2.7 mm screws may damage the articular surface of the joint and the tip of the plate may prevent full elbow extension. It is essential to check both of these before committing to a final plate position.
- It is important to insert the 2.7 mm locking head screws with the correct threaded drill guide and drill with a 2.0 mm drill bit.
- Conventional or locking head screws can be used in the 3.5 mm combination holes, using the techniques described above for the LCP reconstruction plate.

Both plate types:
- In all LCP locking plates it is important to have a threaded drill guide that has not been previously damaged. It must be perfectly positioned in the threaded part of the combination hole to prevent both cross-threading of the screw at insertion and damage to the threaded drill guide.
- The torque-limiting screwdriver must be used to insert and particularly tighten all locking head screws to prevent difficulty with removal.
- If the screws are too long and intraoperative imaging shows they have penetrated the joint surface, a conventional screwdriver may help with removal.
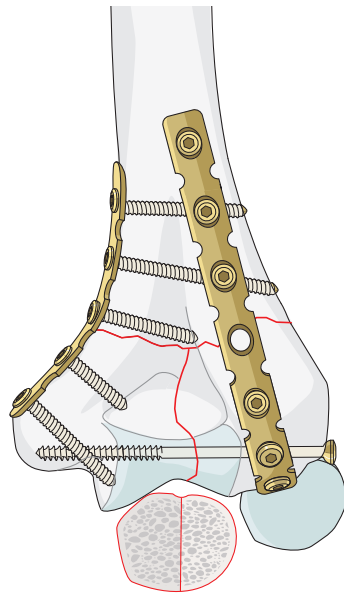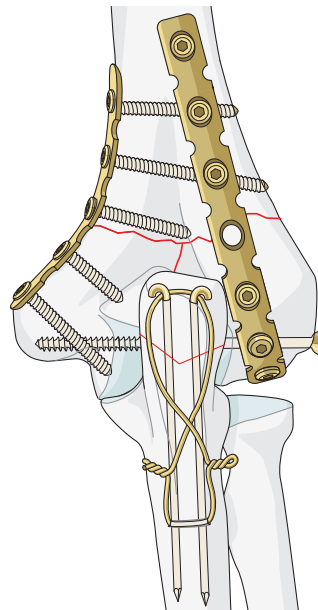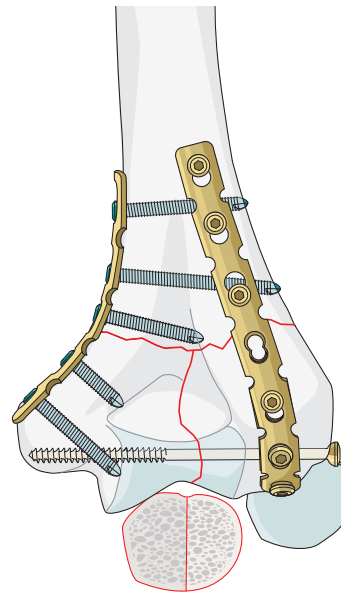
Fig 3.5-6f	Fig 3.5-6g	Fig 3.5-7	Fig 3.5-8
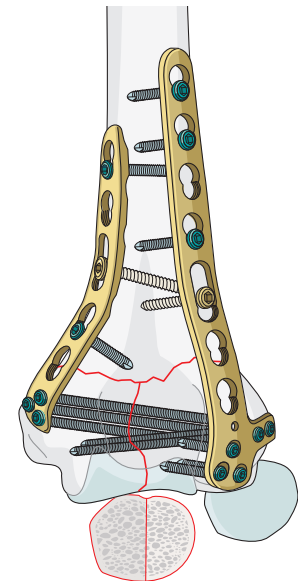
- Locking head screws do not provide any compression of fracture fragments. If compression of articular or simple oblique fractures is required, conventional screws are required.
- If a combination of locking head and conventional screws is to be used, then the order of screw insertion must be carefully planned. As a rule, conventional screws must be inserted first.
- Locking head screws placed through a threaded locking hole of a plate can only be directed in the specific path determined

by the hole. It is therefore vital to check the position of the two plates to ensure screws from each plate are not directed toward each other.

Further information is available on AO Teaching video 20162: Intraarticular Type C Fracture of the Distal Humerus (Foamed Elbow).

9 Specific perioperative care

- Make sure the airway is secured and the anesthetist has appropriate access.
- Surgical time may well exceed safe tourniquet inflation time. Therefore it may be best to avoid using a tourniquet.
- Be careful with the pressure areas, especially in elderly patients.
- Confirm that the patient is securely positioned on the operating table and that the nonoperative arm is appropriately positioned and supported.

- Ensure that the elbow can be flexed to at least 90º and that there is adequate access for the image intensifier before draping.
- Maintain sterility as the image intensifier is rotated around the surgical field.

10 Specific postoperative care

- X-rays must be taken postoperatively to check and document the reduction and position of the implants unless adequate hard copies or images can be saved or printed from the image intensifier.
- The fixation should allow safe general lifting and handling of the patient for nursing.

- Elbow movement should normally start early under physiotherapy supervision, but may need to be restricted until skin healing has occurred.
- In the elderly, rehabilitation is often limited by other medical conditions and the patient's ability to be cooperative and compliant.

Author   Bruce Twaddle

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Have 4.0 mm cannulated screw options and optional plates 3.5 for distal humerus ready.
- Be prepared for an osteotomy and tension band wiring of the olecranon.
- Make sure appropriate drill bits are available.
- Remember vessel loops for nerve identification.
- Be prepared for application of different types of screws.
- Discard used K-wires.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Detailed preoperative planning makes a successful operation much more likely and is therefore mandatory.
- Good patient set-up is essential particularly making sure that adequate range of motion of the elbow is possible, ideally at least 90° of flexion.
- Ensure appropriate imaging is achievable before preparation and draping of the injured extremity.
- Plan the exposure using an olecranon osteotomy if required for adequate visualization. Perfect reduction of the articular surface is essential.
- Identify and protect the ulna nerve with a vascular loop.
- Use of K-wires is important for provisional reduction of the joint segment and then connecting this to the rest of the humerus.
- Carefully plan the placement of plates and contour these as accurately as possible using the malleable templates.
- Be sure interference of screws from two plates does not displace the fracture by careful checking, using intraoperative imaging.
- All threads of any partially threaded cancellous lag screws must cross beyond the fracture line so as to allow compression at the fracture site.
- Plan for tension band wiring of an olecranon osteotomy.
- Check that the final fixation does not penetrate the articular surface or impair full motion of the elbow.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.6   Olecranon fractures

Author   Shaul Beyth

3.6   Olecranon fractures

Implants and surgical techniques

- Tension band wiring—1.0 or 1.25 mm cerclage wire and 1.6 or 1.8 mm K-wires
- LC-DCP 3.5

Cases

- Transverse olecranon fracture (21-B1)
- Comminuted olecranon fracture (21-B1)

Introduction

- Müller AO/OTA Classification divides proximal forearm fractures into three groups:
  - type 21-A: extraarticular fracture
  - type 21-B: articular fracture of one bone
  - type 21-C: articular fracture of both bones
- Fractures involving both the proximal radius and ulna are unusual but are serious injuries that frequently require surgical intervention. These injuries are not described.
- Fractures of the olecranon are usually caused by direct trauma, a sudden and extreme load to the extensor mechanism of the elbow, or a combination of both. This causes detachment of the bony insertion of the triceps tendon from the proximal ulna and results in discontinuity of the extensor mechanism of the elbow joint.
- Open olecranon fractures are uncommon, but overlying soft-tissue injuries such as abrasions and skin contusions are frequent.

- There are major differences in the severity, treatment, and outcome of transverse and comminuted fractures of the olecranon. A transverse fracture is essentially an avulsion fracture (often in osteoporotic bone) triggered by minor direct trauma, whereas the comminuted olecranon fracture is the result of local high-energy transfer.
- The tension band technique is only appropriate when the fracture is simple and when there is no fragmentation of the articular surface (see chapter 2.4.4). It may be achieved by using a figure-of-eight wire to compress the fragments together. An intramedullary screw or K-wires are used to ensure that this compression is optimally applied at the fracture site.
- Comminuted fractures in which the olecranon is broken in more than one site or when the fracture line extends distal to the articular surface are not suitable for the tension band technique, and should therefore be stabilized by means of a plate and lag screws.
- Management of a multifragmentary articular fracture can be difficult and surgery should be proceeded by careful planning.

Müller AO/OTA Classification of proximal radius/ulna fractures—olecranon fracture

21 radius/ulna, proximal

| 21-A1 | 21-A2 | 21-A3 | 21-B1 | 21-B2 | 21-B3 | 21-C1 | 21-C2 | 21-C3 |

21-A   extraarticular fracture
21-A1   ulna fractured, radius intact
21-A2   radius fractured, ulna intact
21-A3   both bones

21-B   articular fracture
21-B1   ulna fractured, radius intact
21-B2   radius fractured, ulna intact
21-B3   one bone articular fracture,
         other extraarticular

21-C   articular fracture of both bones
21-C1   simple
21-C2   one articular simple, other articular
         multifragmentary
21-C3   multifragmentary

Author   Shaul Beyth

3.6.1   Transverse olecranon fracture (21-B1): stabilization with tension band wiring

Surgical management

- Stabilization with tension band wiring and K-wires 1.6 mm

Alternative implants

- Tension band wiring and 3.5 mm cortex screw

1   Introduction

- Simple transverse fractures occur through the articular surface of the proximal ulna.
- Due to the strong pull on the proximal fragment by the triceps, displacement is characteristic of these fractures.
- The tension band technique harnesses the distraction force of the triceps at the posterior cortex and converts it to compression at the articular cortex (see chapter 2.4.4).

- As this fracture is intraarticular, anatomical reduction, absolute stability, and early movement are required to restore the joint function.
- In patients with poor-quality bone the wires may cut out leading to loss of fixation. Plating or even conservative treatment should be considered as treatment options in this subgroup.

Fig 3.6.1-1a–b
a   Preoperative x-ray: short oblique olecranon fracture.
b   Postoperative x-ray: stabilization with two K-wires and tension band wiring.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instruments
- K-wire selection (size used depends on individual anatomy)
- Cerclage wire 1.0 or 1.25 mm
- Wire instrument set
- Vessel loops
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Board or arm rest to enable positioning of the forearm in supine or lateral position
- Image intensifier
- X-ray protection devices for personnel and patient
- Pneumatic tourniquet (may or may not be inflated)

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- Regional anesthesia may be delivered via:
  – interscalene block
  – brachial plexus block
- While regional anesthesia contributes to postoperative pain management, it makes postoperative neurological evaluation impossible until it is worn off.

Author   Shaul Beyth

4   Patient and x-ray positioning

- Position the patient supine on a radiolucent table.
- Put a radiolucent pad or two-folded sheets under the affected shoulder to make positioning of the elbow across the patient's chest easier (Fig 3.6.1-2).
- Take extreme care to protect the patient's face and eyes before skin disinfection.
- Adjust the operating table to the appropriate height.
- Place the image intensifier screen opposite the surgeon on the other side of the table. Make sure there are no radiopaque objects interfering with elbow imaging.
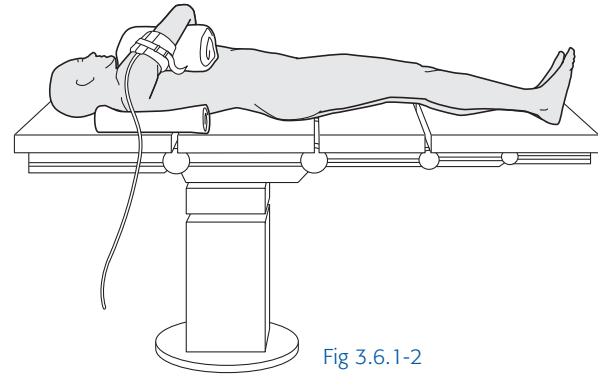
Fig 3.6.1-2

5   Skin disinfecting and draping

- After positioning the patient, disinfect the entire upper limb with the appropriate antiseptic (Fig 3.6.1-3a).
- Drape the upper arm, including the tourniquet. If a sterile tourniquet is used it is applied after draping.
- Drape the hand separately to allow elbow flexion during surgery and imaging (Fig 3.6.1-3b).

- Complete patient draping using single-use drapes or sterile sheets.
- Drape the image intensifier.
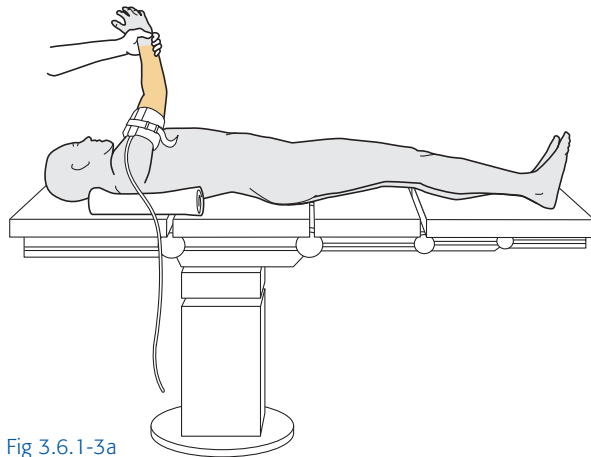
Fig 3.6.1-3a

Fig 3.6.1-3b

6 Operating room set-up

- The ORP and surgeon stand on the side of the injury.
- The assistant stands on the opposite side.
- Place the image intensifier on the same side as the surgeon.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.6.1-4).
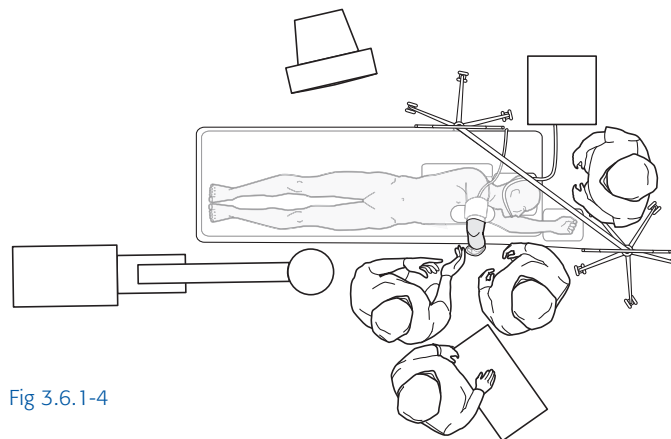
Fig 3.6.1-4

7 Instrumentation
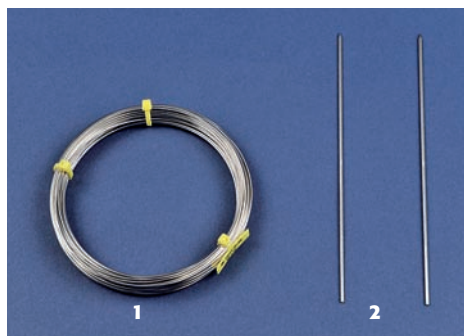
Fig 3.6.1-5a   Implants
1. Coil with cerclage wire 1.25 mm
2. K-wires 1.6–2.0 mm

Fig 3.6.1-5b   Instruments for fracture fixation with tension band wiring
3. Drill bit 2.0 mm
4. Triple drill guide 2.0 mm
5. Reduction forceps with points, medium
6. Reduction forceps with points, large
7. Wire bending pliers
8. Parallel pliers, flat nosed
9. Bending iron for K-wires
10. Impactor for K-wires
11. Wire cutter, large
12. Hammer

Author   Shaul Beyth

8   Procedure and technique—step-by-step

- Incision: make a longitudinal incision over the posterior aspect of the elbow, skirting the point of the olecranon on the radial side, and extending to the proximal third of the ulna.
- Identify and protect the ulnar nerve with vessel loop (dissecting out the nerve is usually not necessary).
- Expose the fracture site and wash it out.
- Expose the elbow joint.
- Drill a monocortical hole using a 2.0 mm drill bit for the reduction forceps in the posterior aspect of the proximal ulnar shaft, about 2–3 cm distal to the fracture site (Fig 3.6.1-6a).

- Reduce the fracture with a pointed reduction forceps with one end anchored in the predrilled hole, and apply mild compression to achieve provisional reduction (Fig 3.6.1-6b).
- Insert two parallel 1.6 mm K-wires using the triple drill guide from the proximal fragment to the anterior cortex of the distal fragment, just distal to the coronoid process. Do not advance wires beyond the anterior cortex (Fig 3.6.1-6c–d).
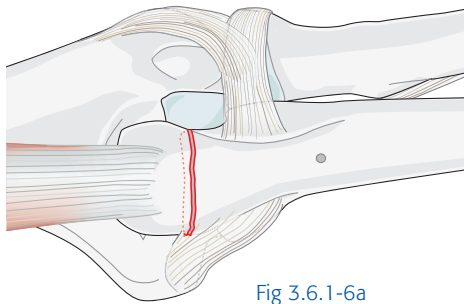
Fig 3.6.1-6a
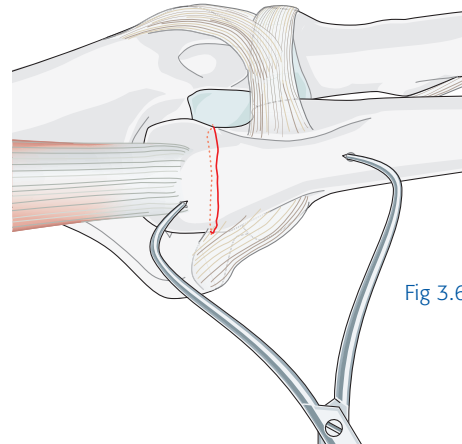
Fig 3.6.1-6b
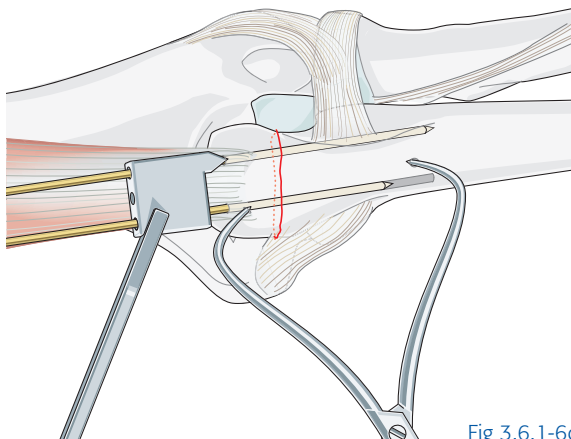
Fig 3.6.1-6c
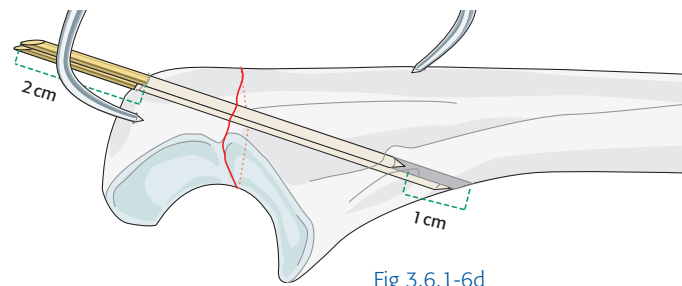
Fig 3.6.1-6d

- Confirm accurate reduction of the fracture and placement of the K-wires using the image intensifier. A lateral view may be achieved by rotating the C-arm to a horizontal position and internally rotating the shoulder.
- Using a 2.0 mm drill bit and the triple drill guide, drill a transverse bicortical hole across the posterior cortex of the distal fragment 3–4 cm distal to the fracture (Fig 3.6.1-6e).
- Pass the ~ 300 mm cerclage wire 1.25 mm through the hole and loop it around the two K-wires, ensuring that it passes deep to the tendon of the triceps creating a figure-of-eight.
- Twist a small loop in the cerclage wire (to enable simultaneous tightening from both sides) on one side and bring the two ends together on the other (Fig 3.6.1-6f).

- Gradually tighten both sides of the cerclage wire by twisting the wire using the parallel pliers. Ensure tension on each side is kept equal (Fig 3.6.1-6g).
- Pull K-wires a few millimeters back, cut them short, and bend them back like a hook.
- Impact K-wires into the bone with the bent ends over the cerclage wire and hammer them home with a punch to reduce the risk of their backing out.
- Shorten twists of the tension band wire by cutting off the surplus and bend the ends over to lie flat on the ulna (Fig 3.6.1-6h).
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 00132: Olecranon-Transverse Fracture 21-B1 Tension Band Wiring.
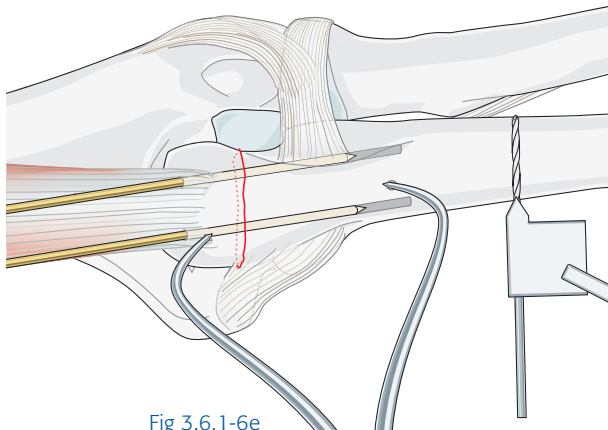
Fig 3.6.1-6e

Fig 3.6.1-6f

Author   Shaul Beyth
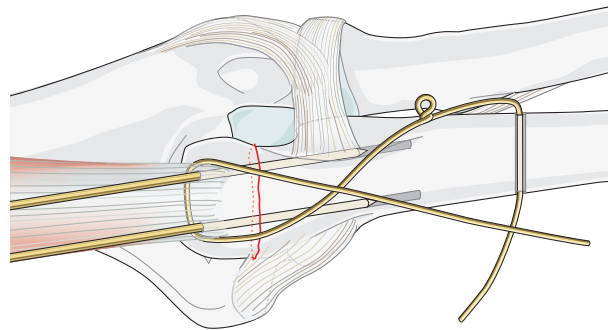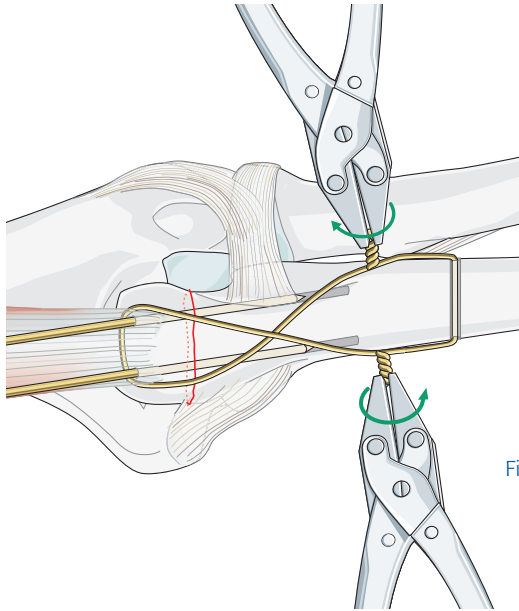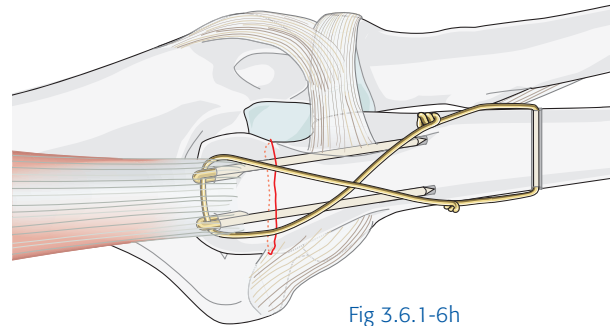
Fig 3.6.1-6g

Fig 3.6.1-6h

9   Specific perioperative care

- Make sure tourniquet cuff is well padded, the correct width for the size of the arm is applied, and inflation pressure set appropriately to avoid neuropraxia.
- Avoid having the tourniquet inflated for too long during surgery.
- Avoid placing instruments on the patient's chest and abdomen.

10   Specific postoperative care

- Take x-rays for documentation and follow-up purposes if image intensification cannot be adequately saved or are of poor quality.
- Fixation should allow early mobilization of the elbow.

- Make the patient aware of the presence of the subcutaneous wires and avoid applying pressure on the olecranon until removal of hardware.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Remember the vessel loops.
- Check that implants for plating (see Fig 3.6.2-6) are available, as this is the salvage procedure for tension band failure.

- Have two bending pliers available to ensure simultaneous tightening of the tension band wire, thus producing a more balanced pressure at the fracture site.
- Discard used wires and cut pieces.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Fracture reduction is made easier by extending the elbow and bringing the distal to the proximal fragment.
- An inflated tourniquet can trap some of the bulk of triceps and make reduction difficult.
- Accurate restoration of the articular surface may be assumed if the posterior cortex is anatomically reduced. It can be checked with the image intensifier.
- Keep the entry point of K-wires in the proximal fragment as far apart as possible to enhance fixation stability, but ensure they are parallel.

- Do not advance wires beyond the anterior cortex of the ulna; they could injure the anterior neurovascular structures.
- Make sure all sharp edges left after shortening wires are well buried to avoid skin irritation and wound infection.
- Beware of flying metal pieces when cutting wires.
- Inform the patient preoperatively that wires commonly back out and need removal once the fracture has healed.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Shaul Beyth

3.6.2   Multifragmentary olecranon fracture (21-B1): stabilization with LC-DCP 3.5

Surgical management

- Stabilization with LC-DCP 3.5

Alternative implants

- One-third tubular plate 3.5
- LCP 3.5
- DCP 3.5
- Conventional or LCP reconstruction plate 3.5
- LCP metaphyseal plate 3.5 for distal medial humerus

1   Introduction
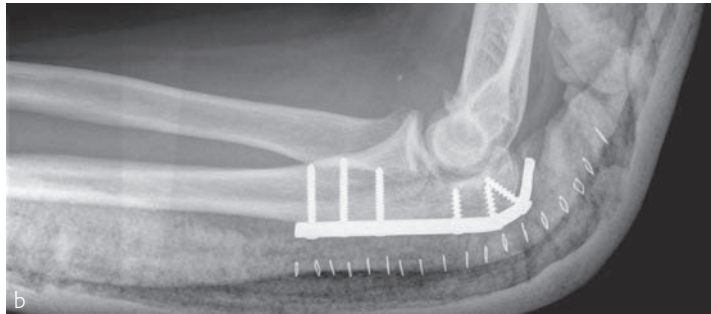
- Multifragmentary fractures occur through articular surface of the proximal ulna.
- Displacement is due to the strong pull of the triceps on the proximal fragment.
- Not suitable for tension band technique because the fracture is multifragmentary.
- Anatomical reduction and early movement are required to restore joint function.
- in patients with poor-quality bone, locked screws are preferable.

Fig 3.6.2-1a–b
a   Preoperative x-ray: multifragmentary olecranon fracture.
b   Postoperative x-ray: stabilization with LC-DCP 3.5.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- LC-DCP 3.5 small fragment set—instruments, screws, and plates
- K-wire selection
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Board or arm rest to enable positioning of the forearm in supine or lateral positions
- Image intensifier
- X-ray protection devices for personnel and patient
- Pneumatic tourniquet (may or may not be inflated)

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- Regional anesthesia may be delivered via:
  - interscalene block
  - brachial plexus block
  - intravenous Bier block
- While regional anesthesia contributes to postoperative pain management, it makes postoperative neurological evaluation impossible until it is worn off.

Author   Shaul Beyth

4   Patient and x-ray positioning

- Position the patient supine on a radiolucent table (Fig 3.6.2-2).
- Put a radiolucent pad or two-folded sheets under the affected shoulder to make positioning of the elbow across the patient's chest easier.
- Take extreme care to protect the patient's face and eyes before skin disinfection.
- Adjust the operating table to an appropriate height.
- Place the image intensifier screen opposite the surgeon on the other side of the table. Make sure there are no radiopaque objects interfering with elbow imaging.
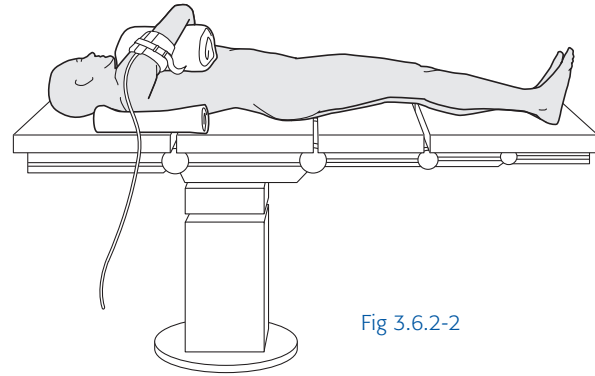
Fig 3.6.2-2

5   Skin disinfecting and draping

- Disinfect the exposed area with the appropriate antiseptic (Fig 3.6.2-3a).
- Drape the upper arm, including the tourniquet. If a sterile tourniquet is used applied it after draping (Fig 3.6.2-3b).
- Drape the hand to allow elbow flexion during surgery and imaging.

- Complete patient draping using single-use drapes or sterile sheets.
- Drape the image intensifier.
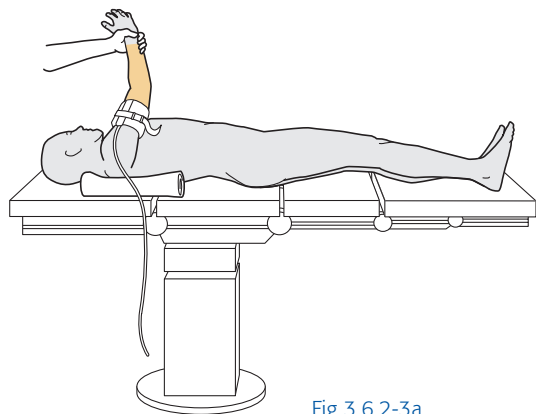
Fig 3.6.2-3a

Fig 3.6.2-3b

6   Operating room set-up

- The ORP and surgeon stand on the side of the injury.
- The assistant stands on the opposite side.
- Position the image intensifier on the same side as the surgeon.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.6.2-4).
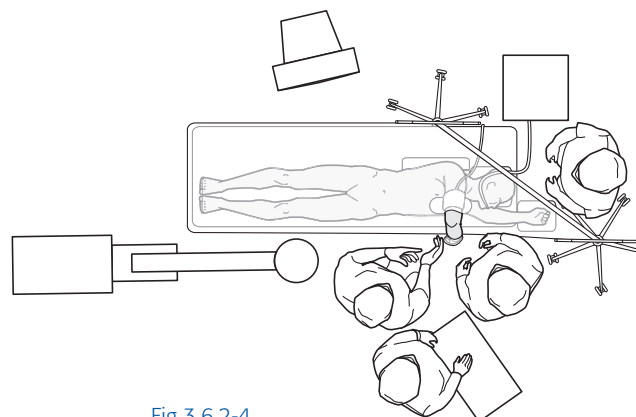
Fig 3.6.2-4

7   Instrumentation
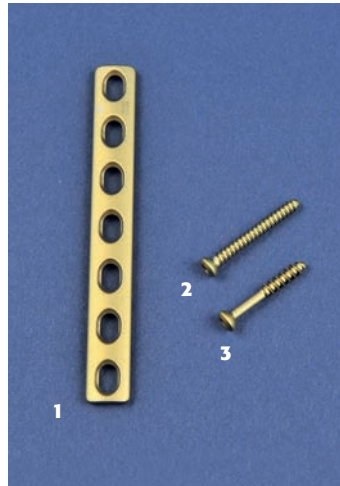
Fig 3.6.2-5a Implants
1.   LC-DCP 3.5, 7 holes
2.   Cortex screw 3.5 mm
3.   Cancellous bone screw
      4.0 mm, partially threaded

Fig 3.6.2-5b   Instruments for fracture fixation with LC-DCP 3.5
4.   K-wires 1.6 mm (temporary fixation)
5.   Triple drill guide 2.0 mm
6.   Drill bit 3.5 mm
7.   Drill bit 2.5 mm
8.   Universal drill sleeve 3.5 mm
9.   Double drill sleeve 3.5/2.5 mm
10.   LC-DCP drill sleeve 3.5 mm

11.   Depth gauge
12.   Tap 3.5 mm
13.   Tap 4.0 mm
14.   T-handle with quick coupling
15.   Screwdriver shaft
16.   Screwdriver with holding sleeve

Fig 3.6.2-5c   Instruments for reduction and contouring
17.   Reduction forceps with points, large
18.   Reduction forceps with points, medium
19.   Bending pliers for plates
20.   Bending iron for plates (two)
21.   Bending template for LC-DCP 3.5

8 Procedure and technique—step-by-step

- Incision: make a longitudinal incision on the posterior aspect of the elbow, skirting the point of the olecranon on the radial side, and extending to the proximal third of the ulna.
- Identify and protect the ulnar nerve with a vessel loop. Dissecting out the nerve may be necessary depending on the extent of the fracture.
- Expose the fracture site and wash it out.
- Expose the elbow joint.
- Identify fragments that make up the articular surface.
- Use a pointed reduction forceps to reduce articular surface fragments and to restore articular congruency.

- Temporarily stabilize the reduced articular fragments with K-wires (Fig 3.6.2-6a).
- Reduce the remaining fracture fragments, using either K-wires or pointed reduction forceps to obtain provisional stability.
- Check anatomical reduction carefully with the image intensifier.
- Choose an LC-DCP 3.5 of appropriate length (usually 8–9 holes) and bend it to match the ulnar contour (Fig 3.6.2-6b). Accurate contouring of the plate is essential.
- In some cases a one-third tubular or a reconstruction plate may be more suitable, as it is easier to contour when considerable bending is required.
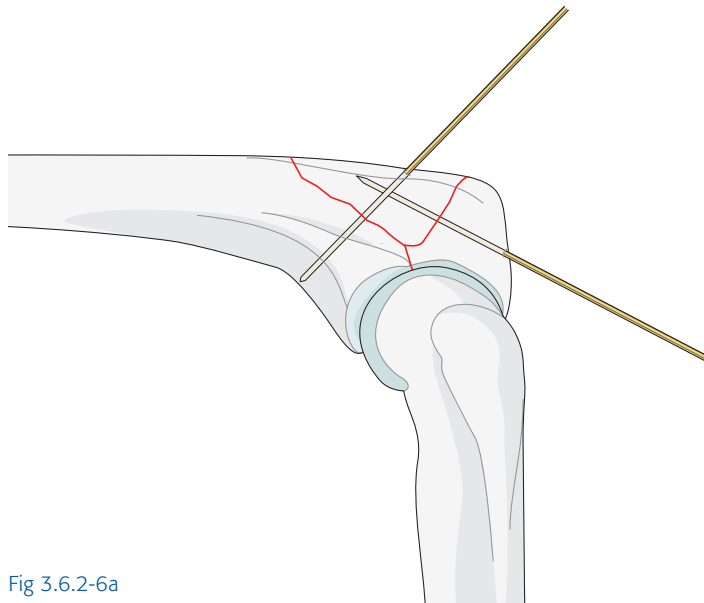
Fig 3.6.2-6a

Fig 3.6.2-6b

Author   Shaul Beyth
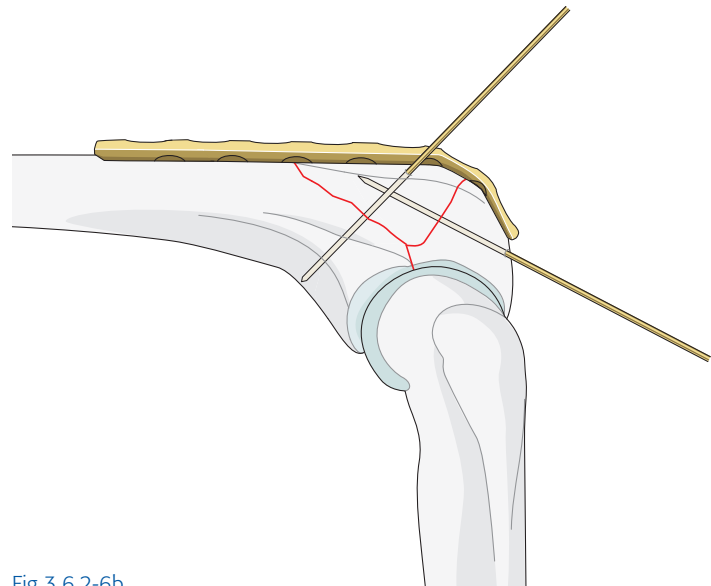
- Fix the plate firmly to the proximal main fragment with 4.0 mm cancellous bone screws. Drill a 2.5 mm hole using the universal drill guide (or LC-DCP 3.5 double drill guide, green) in the neutral (spring pushed-in) position, measure the depth, tap the hole with the 4.0 mm (silver) tap, and insert a 4.0 mm cancellous bone screw of appropriate length (Fig 3.6.2-6c).
- Be careful not to penetrate the articular surface of the joint with the drill or screw.
- It may be appropriate to apply some compression across the fracture site while fixing the distal end of the plate. This can be done by tightening the pointed reduction forceps holding the reduction and/or by putting the first distal fragment screw in as a compression screw. Whether and how to apply compression will depend on the exact configuration of the fracture.
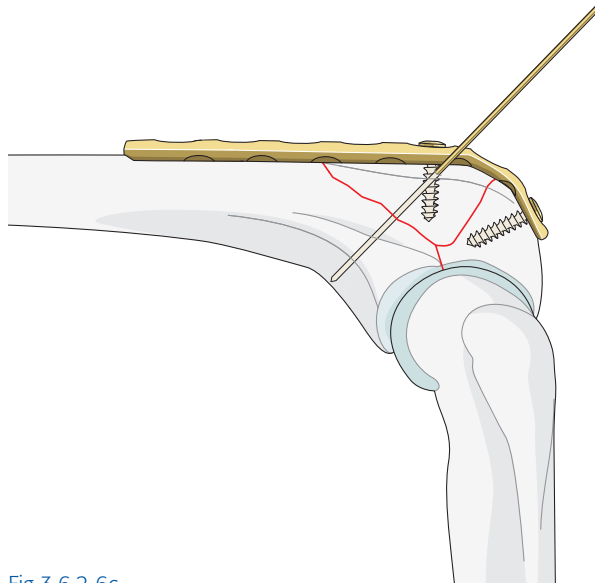
- Drill the first distal screw hole with a 2.5 mm drill bit with the universal drill guide (or LC-DCP 3.5 double drill guide, green) in the neutral spring (pushed-in) position. Measure the depth and tap the hole with a 3.5 mm (gold) tap. Insert a 3.5 mm cortex screw of appropriate length (Fig 3.6.2-6d). This screw will not apply compression.
- If the first cortex screw in the distal fragment is a compression screw, the 2.5 mm drill hole is placed eccentrically in the plate hole by using the 2.5 mm universal drill guide not pushed down (or LC-DCP 3.5 double drill guide, gold with the arrow pointing toward the fracture) (see chapter 2.4.3). Measure the screw length, tap the hole with the 3.5 mm (gold) tap, and insert the screw. Apply compression across the fracture site as the screw is tightened.
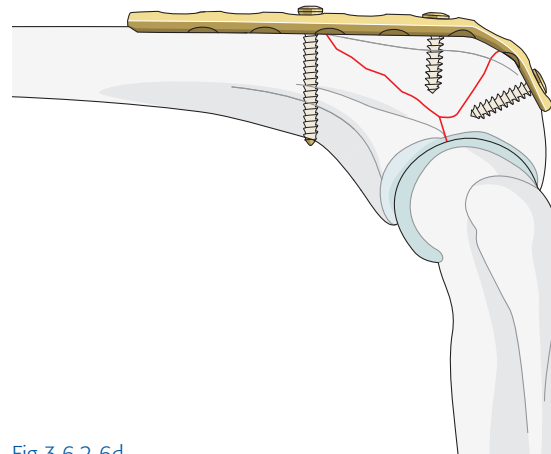
Fig 3.6.2-6c

Fig 3.6.2-6d

- Once the fracture has been reduced (and if required, compressed), insert additional 3.5 mm neutral cortex screws into the distal fragment and 4.0 mm cancellous bone screws into the proximal fragment. Six cortices (at least three screws) should be held distally and if possible three screws used proximally, although there is not always enough space for this (Fig 3.6.2-6e).
- Remove any K-wires and reduction forceps.
- Take and save copies of final x-rays in both planes.
- Close the wound.
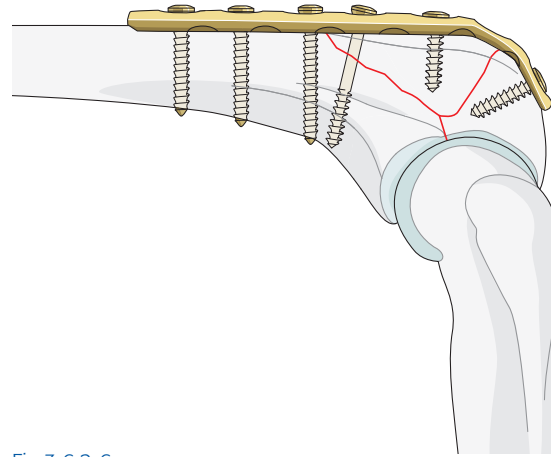
Fig 3.6.2-6e

9 Specific perioperative care

- Make sure the tourniquet cuff is well padded, of the correct width, and the pressure set appropriately to avoid neuropraxia.
- Avoid having the tourniquet inflated for too long during surgery.
- Avoid placing instruments on the patient's chest and abdomen.

10 Specific postoperative care

- Take x-rays for documentation and follow-up purposes if image intensification cannot be saved or are of poor quality.
- Ideally, fixation should be sufficiently strong to enable immediate elbow mobilization; however, this is often not the case.
- Posterior splint or above elbow cast may be required postoperatively to protect fixation and for the patient's comfort.

- Make the patient aware of the subcutaneous implant and avoid applying pressure on the olecranon until removal of hardware.

Author Shaul Beyth

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of instruments and implants are available.
- Surgical exposure for plating is usually larger than for tension band wiring.

- Have alternative plates 3.5 available.
- Check the screw length and type. It is easy to confuse cortex and cancellous bone screws.
- Check that the tap is appropriate for the particular screw type. Gold for cortex screws and silver for cancellous bone screws.
- Document and reorder all implants used.

12 Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Fracture reduction is made easier by extending the elbow and bringing the distal to the proximal fragment.
- An inflated tourniquet can trap the triceps muscle and may make fracture reduction more difficult.
- These fractures can be difficult to assess on x-ray, and even a careful preoperative plan may require adaption.
- Anatomical restoration of the articular surface has to be done under direct vision and not assumed if the posterior cortex is accurately reduced, as the fracture is multifragmentary.
- Check screw length carefully to avoid penetration into the joint.

- It is sometimes necessary to use interfragmentary lag screws to incorporate any large, separate fragments of the olecranon articular surface into a single large proximal olecranon fragment before applying the plate. Ensure that the heads of any lag screws do not lie in the way of subsequent plate placement.
- If the bone is of poor quality, using an LCP or reconstruction LCP allows the use of locking screws once a conventional screw has been inserted each side of the fracture. This makes the fixation stronger and may allow for earlier mobilization. Locking screws should not be inserted until any compression has been applied across the fracture.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.7 Forearm shaft fractures

Author   Mariusz Bonczar

3.7   Forearm shaft fractures

Case

- Simple fracture of both bones fixed with LC-DCP 3.5

Introduction

- The Müller AO/OTA Classification divides forearm shaft fractures into three types:
  - type 22-A: simple fracture of one or two bones
  - type 22-B: wedge fracture of one or two bones
  - type 22-C: complex fracture of one bone and simple fracture of the other or complex fracture of both bones
- The function of the arm is to position the hand in space. The forearm not only contributes to flexion and extension of the arm but is also responsible for all rotational positioning of the hand.
- Forearm rotation occurs as the radius to which the wrist and the hand are attached rotates around the immobile ulna. Proximally, rotation occurs at the proximal radioulnar joint; distally, at the distal radioulnar joint. In the supine position the radius and ulna lie almost parallel, but in pronation the radius crosses the long axis of the ulna (Fig 3.7-1a).
- Rotation is dependent on the shape of the forearm bones as well as on the integrity of the proximal and distal radioulnar joints. The forearm is in effect a complex joint.
- To maintain full rotation, forearm shaft fractures require accurate anatomical reduction.
- Disturbance in fracture healing, axial or rotational deformities, or healing with excessive callus will result in a loss of rotation; thus affecting hand function.
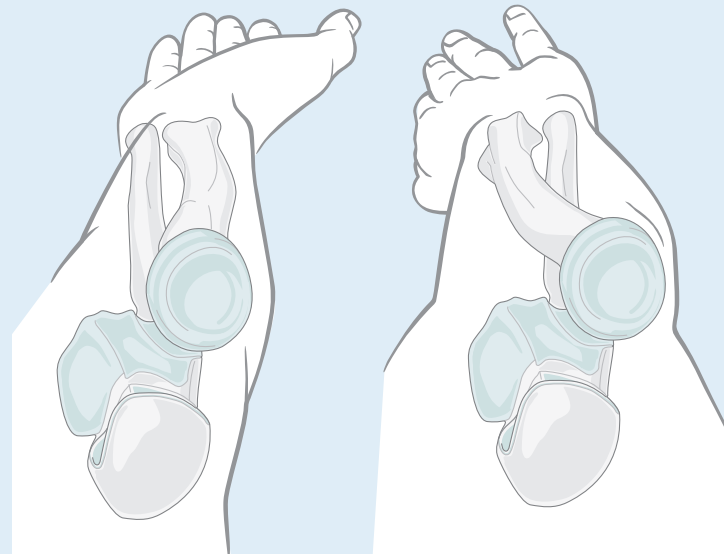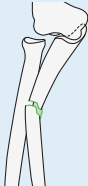
Fig 3.7-1a   Left, forearm in supination—radius and ulna are parallel. Right, forearm in pronation—radius crosses long axis of ulna.

- Isolated, completely undisplaced fractures of one bone may be treated conservatively. All other forearm fractures in adults require fixation.
- Isolated displaced fractures of the radius are always associated with a dislocation of the distal radioulnar joint and of the ulna with a radial head dislocation. Accurate reduction and fixation of the bone will usually result in reduction of the dislocation, although this must be confirmed with x-ray.

- The radius is more difficult to treat than the ulna because of its curved shape, its irregular cross-section with thick cortices, and its permanent torsional loading.
- Preoperative planning is mandatory.
- When planning fixation, consider not only the bony fracture pattern but also the state of the soft tissues which have been damaged at time of injury.

Müller AO/OTA Classification—forearm shaft fractures

22 radius/ulna, diaphyseal

| 22-A1 | 22-A2 | 22-A3 | 22-B1 | 22-B2 | 22-B3 | 22-C1 | 22-C2 | 22-C3 |

22-A   simple fracture
22-A1   ulna fractured, radius intact
22-A2   radius fractured, ulna intact
22-A3   both bones

22-B   wedge fracture
22-B1   ulna fractured, radius intact
22-B2   radius fractured, ulna intact
22-B3   one bone wedge, other simple or wedge

22-C   complex fracture
22-C1   ulna complex, radius simple
22-C2   radius complex, ulna simple
22-C3   both bones complex

Author   Mariusz Bonczar

3.7.1   Radius and ulna fracture (22-A3): stabilization with LC-DCP 3.5

Surgical management

- Fixation with LC-DCP 3.5

Alternative implants

- DCP 3.5
- LCP 3.5

1   Introduction

- Simple oblique fractures may be fixed with a lag screw reinforced by a protection plate, while transverse ones require the plate to be used as a compression plate. Severe multifragmentary fractures usually require the plate to be used as a bridging plate.
- With poor-quality bone, the use of an LCP and locking screws should be considered. This is not normally necessary in young adults.

Fig 3.7-1b–c
b   Preoperative x-ray: transverse fracture of radial shaft with short oblique fracture of ulna.
c   Postoperative x-ray: stabilization of radius with LC-DCP 3.5. Stabilization of ulna with LC-DCP 3.5.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Side and site of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed/compartment syndrome)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instruments required:
- LC-DCP 3.5 small fragment set, ie, instruments, screws, and plates
- Bending tools
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Operating table with radiolucent arm board attachment
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- If regional anesthesia is used, the surgeon must perform the procedure within the time available before the anesthetic wears off.

Author   Mariusz Bonczar

4 Patient and x-ray positioning

- Position the anesthetized patient supine on the operating table with the affected limb on an attached radiolucent arm board (Fig 3.7-2).
- Take care to protect soft tissues, skin pressure points, and the position of subcutaneous nerves particularly the ulnar nerve at the elbow.
- Adjust the operating table and arm board to the appropriate height.
- Place the image intensifier on the opposite side of the patient's arm opposite the surgeon. To obtain a lateral view the surgeon must rotate the forearm.
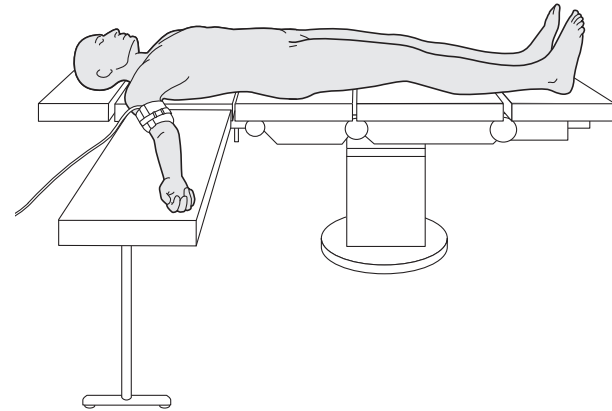
Fig 3.7-2

5   Skin disinfecting and draping

- After positioning the patient and applying an arm tourniquet, disinfect the whole arm including fingertips with the appropriate antiseptic (Fig 3.7-3a).
- Avoid any disinfection fluids running under the tourniquet.

- Apply sterile drapes to ensure a waterproof environment for the operative site. Since a drape around the hand can be bulky, it may be more suitable to wrap the hand in a sterile stockinette fixed with an adhesive tape or a clear adhesive plastic drape (Fig 3.7-3b).
- Drape the image intensifier.

Fig 3.7-3a

Fig 3.7-3b

Author   Mariusz Bonczar
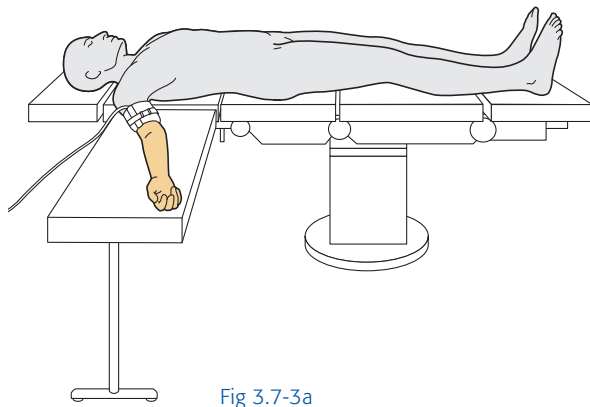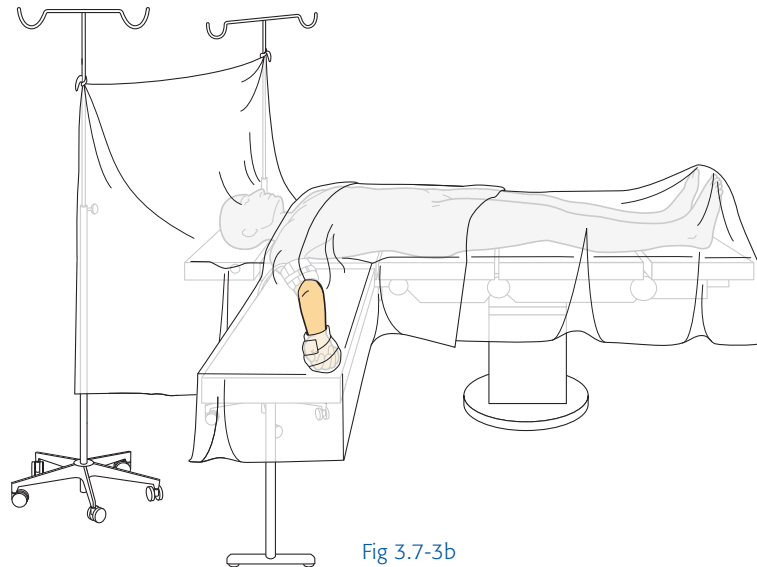
6   Operating room set-up

- The surgeon sits facing the patient's head, the assistant opposite, and the ORP at the end of the arm table.
- Bring the image intensifier in from the assistant's side of the arm table. The assistant has to move temporarily when imaging.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.7-4).
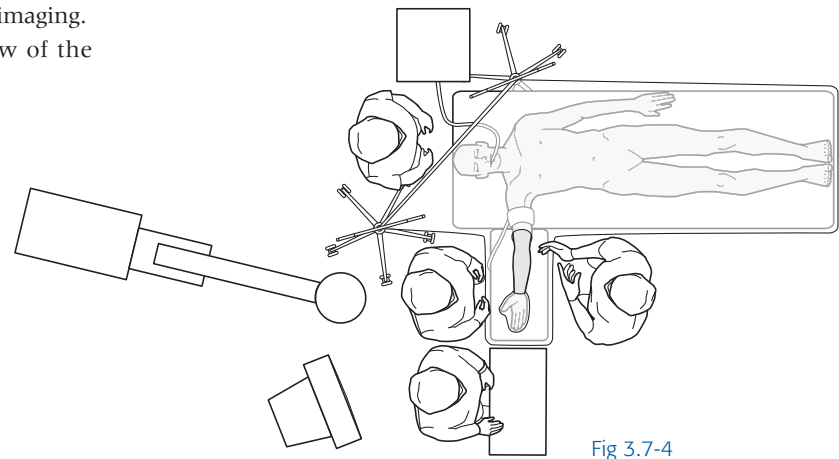
Fig 3.7-4

7 Instrumentation
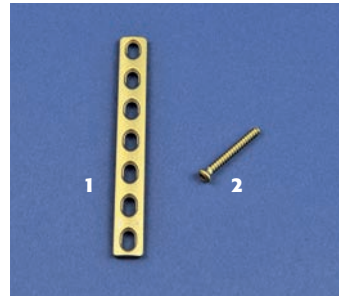
Fig 3.7-5a   Implants
1.   LC-DCP 3.5, 7 holes
2.   Cortex screw 3.5 mm

Fig 3.7-5b   Instruments for fracture fixation with LC-DCP 3.5
3.   Drill bit 3.5 mm
4.   Drill bit 2.5 mm
5.   Universal drill sleeve 3.5 mm
6.   Double drill sleeve 3.5/2.5 mm
7.   LC-DCP drill sleeve 3.5 mm
8.   Countersink 3.5 mm
9.   Depth gauge
10.   Tap 3.5 mm for cortex screws
11.   T-handle
12.   Screwdriver shaft
13.   Screwdriver with holding sleeve

Fig 3.7-5c   Instruments for reduction and contouring
14.   Reduction forceps with points
15.   Bending pliers for plates
16.   Bending iron for plates (two)
17.   Bending template for LC-DCP 3.5

- Incision: the radius and ulna are fixed through two separate incisions to reduce the risk of cross-union between the two bones.
- Two approaches are commonly used to approach the radius. The volar approach (Henry) is performed with the forearm in a fully supinated position with the forearm lying flat on an arm board. The dorsal approach (Thompson) is performed with the forearm in supination. Both approaches are complex and several vital structures are potentially at risk. Consulting standard reference books on approaches or anatomy is therefore advisable if the surgical team is not familiar with the approach to be used.
- The ulna is approached over its dorsomedial subcutaneous border. To obtain access to the bone, flex the forearm at the elbow. The forearm is then held vertically by the assistant.

Radius fixation

Plate applied as neutralization plate:
- Both bones should be exposed and reduced before fixing either of them. Fixing one first may make reduction of the other impossible.
- Obtain reduction by manipulating the bone with pointed reduction forceps. Take care to preserve as many soft-tissue attachments as possible.
- Hold reduced fractures gently with reduction forceps (Fig 3.7-6a).
- If a lag screw is used, drill a gliding hole in the near cortex perpendicular to the fracture line using a 3.5 mm drill bit with corresponding drill guide (Fig 3.7-6b).
- Insert the 2.5 mm drill guide into the hole and drill a 2.5 mm hole in the far cortex.
- Countersink the hole in the near cortex, measure the screw length with the depth gauge, and tap the far cortex with a cortical (gold-colored) tap.
- Insert the appropriate length 3.5 mm cortex screw and tighten it, being careful not to over tighten and strip the thread (Fig 3.7-6c).
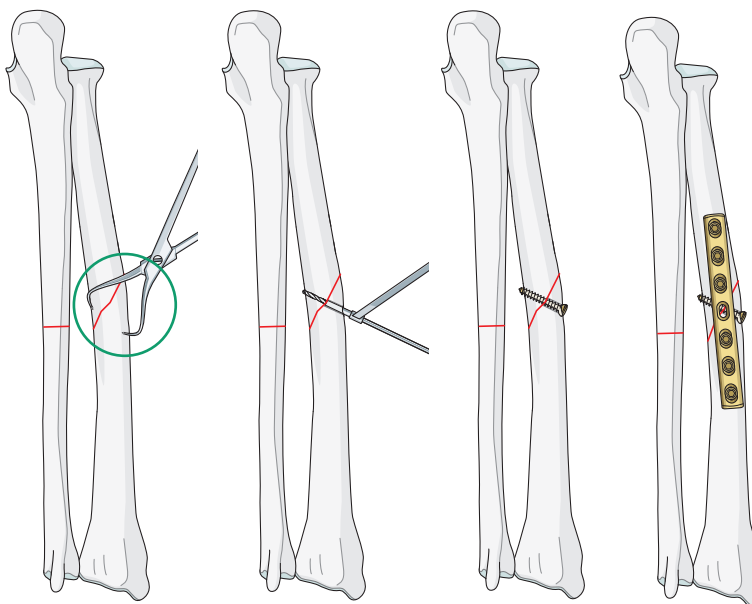
Fig 3.7-6a   Fig 3.7-6b   Fig 3.7-6c   Fig 3.7-6d

- Contour the appropriate LC-DCP 3.5 (6–9 holes) accurately. The plate should have at least three bicortical screws on each side of the fracture.
- Gently hold the plate in position with a finger. This is usually less traumatic than attempting to hold the plate onto the bone with clamps which can cause considerable soft-tissue stripping.
- Insert all screws in the neutral position with the LC-DCP drill guide (green) and drill with the 2.5 mm drill bit through both cortices. Measure the depth and cut the thread with the 3.5 mm cortical (gold-colored) tap. Insert and tighten the screw (Fig 3.7-6d).
- At the end, further tighten all screws. Taking care not to over tighten and strip the screw thread.

Ulna fixation

Plate applied as compression plate:

- If the fracture is short oblique or transverse, compression plating is required.
- Precontour and prebend the middle section of the LC-DCP 3.5 (6–9 holes). Hold it in position across the reduced fracture site (Fig 3.7-6e). A minimum of three bicortical screws are required on each side.
- Insert the first screw in the neutral position with the LC-DCP drill guide (green), with the arrow pointing toward the fracture, and drill with the 2.5 mm drill bit through both cortices. Measure the depth and cut the thread with the 3.5 mm cortical (yellow) tap. Insert and tighten the screw.
- Drill a second hole in the opposite main fragment in the compression mode using the eccentric (yellow) drill guide with the arrow pointing toward the fracture (Fig 3.7-6f).

- Measure the depth and cut the thread with the 3.5 mm cortical (yellow) tap. When the appropriate 3.5 mm cortex screw is tightened, it applies compression across the fracture site (see chapter 2.4.2). Confirm the reduction of the fracture under image intensification.
- Fill remaining screw holes with 3.5 mm cortex screws in the neutral mode (Fig 3.7-6g).
- Check range of rotation of the forearm after completion of both osteosyntheses. If the fixation was accurate, then full supination and pronation of the forearm should be possible.
- Take and save copies of final x-rays.
- Close the wounds.

Further information is available on AO Teaching video 00133: Forearm Shaft Fracture 22-C1 3.5 LCP (8 and 11 holes).
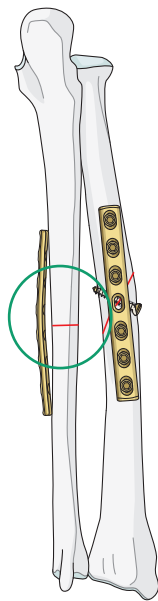
Fig 3.7-6e
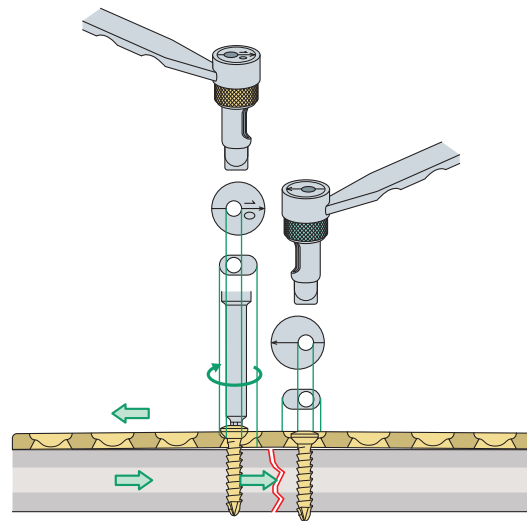
Fig 3.7-6f
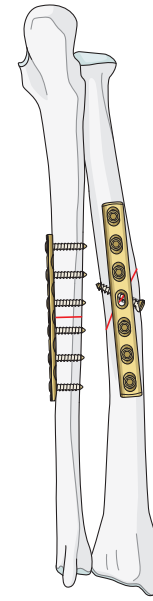
Fig 3.7-6g

Author   Mariusz Bonczar

9   Specific perioperative care

- Be careful with pressure areas particularly when subcutaneous nerves are at risk around the elbow.
- Ensure tourniquet is correctly applied and inflated to correct pressure, and not left inflated for too long.
- Maintain sterility as the image intensifier is rotated around the surgical field.

10   Specific postoperative care

- Carefully observe the arm postoperatively to ensure early detection of a compartment syndrome should it occur.
- Take x-rays postoperatively to check and document reduction and position of implants; unless adequate images were taken from the image intensifier.
- Fixation should allow early active mobilization of wrist, hand, and elbow, including forearm rotation which should start as soon as possible postoperatively. A splint is not normally required.
- Encourage patients to use their hand but cautioned against heavy lifting for at least 6–12 weeks after surgery, depending on follow-up x-rays.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check screw length and type. It is easy to confuse cortex screws and cancellous bone screws.
- Check that the tap is appropriate for the particular screw type. Gold for cortex screws and silver for cancellous bone screws.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Have a detailed plan and tactic drawn up for the operation.
- Decide which fracture to fix first (usually the easiest one) and know the mode in which the plate is being used (protection, compression, or bridging) and the order of screw insertion for each fracture.
- Ensure satisfactory patient set-up.
- Ensure clear x-rays can be obtained in both planes.
- Carefully handle soft tissues and fracture fragments to maintain blood supply and avoid devitalization.
- Reduce both fractures before fixation.
- Check and record distal nerve function after surgery.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.8 Distal radial fractures

Author   Martin Wood
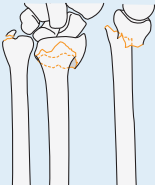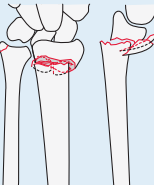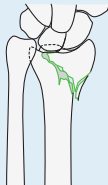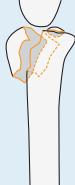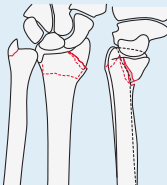
3.8   Distal radial fractures

Implants and surgical technique

- T-plate 3.5, right-angled
- Small external fixator
- LCP distal radius plate 2.4

Cases

- Partial articular fracture (23-B3)
- Complex distal radial fracture (23-C2)
- Complex distal radial fracture (23-C3)

Introduction

Wrist fractures are classified into three groups:
- type 23-A: extraarticular fractures (including 23-A1 ulna only)
- type 23-B: partial articular fractures of the radius
- type 23-C: complete articular fractures of the radius

Fractures are further classified according to the pattern of the fracture or the degree of fragmentation.

- Most distal radius fractures occur in elderly patients with osteoporosis following a simple fall.
- In younger patients they are usually associated with higher-energy trauma.
- Depending on the fracture configuration distal radius fractures can be treated by closed manipulation and splinting, percutaneous K-wire fixation, and external or internal fixation. Unstable fracture types are increasingly being treated with internal fixation, although there is currently little evidence that this is better than K-wire fixation in the long term.
- If an acceptable fracture reduction cannot be achieved and/or maintained after closed manipulation, consider fixation with or without open reduction.
- Incongruence of the articular surface can lead to posttraumatic arthritis in younger patients. In elderly people symptomatic arthritis rarely develops.

- Malalignment with loss of radial length and/or loss of the normal distal radial inclination can lead to static wrist instability with symptoms of weakness and loss of range of movement.
- Failure to restore radial length is a predictor of a poor outcome.
- For a simple partial articular fracture with volar displacement a buttress plate applied to the volar aspect of the radius will maintain reduction.
- For a more complex intraarticular fracture, an anatomically contoured locking plate can be used. A more rigid fixation of the styloid fragment can be achieved by adding a styloid buttress plate.
- In complex multifragmentary fractures, especially with poor-quality bone, it may not be possible to reduce all fragments and hold them with a plate. In such circumstances a bridging external fixator can be used to obtain reduction and alignment of the fracture by ligamentotaxis.
- In the presence of severe soft-tissue damage, an external fixator may be preferable to a plate.

Müller AO/OTA Classification—distal radial fractures

23 radius/ulna, distal

| 23-A1 | 23-A2 | 23-A3 | 23-B1 | 23-B2 | 23-B3 | 23-C1 | 23-C2 | 23-C3 |

23-A   extraarticular fracture
23-A1   ulna fractured, radius intact
23-A2   radius, simple and impacted
23-A3   radius, multifragmentary

23-B   partial articular fracture of radius
23-B1   sagittal
23-B2   coronal, dorsal rim
23-B3   coronal, palmar rim

23-C   complete articular fracture of radius
23-C1   articular simple, metaphyseal simple
23-C2   articular simple, metaphyseal multifragmentary
23-C3   articular multifragmentary

Author   Martin Wood

3.8.1   Partial articular fracture (23-B3): stabilization with T-plate 3.5, right-angled

Surgical management

- Stabilization with T-plate 3.5, right-angled

Alternative implants

- T-plate 3.5, oblique-angled
- LCP T-plate 3.5, right-angled
- LCP volar plates 3.5, 2.7, or 2.4

1   Introduction
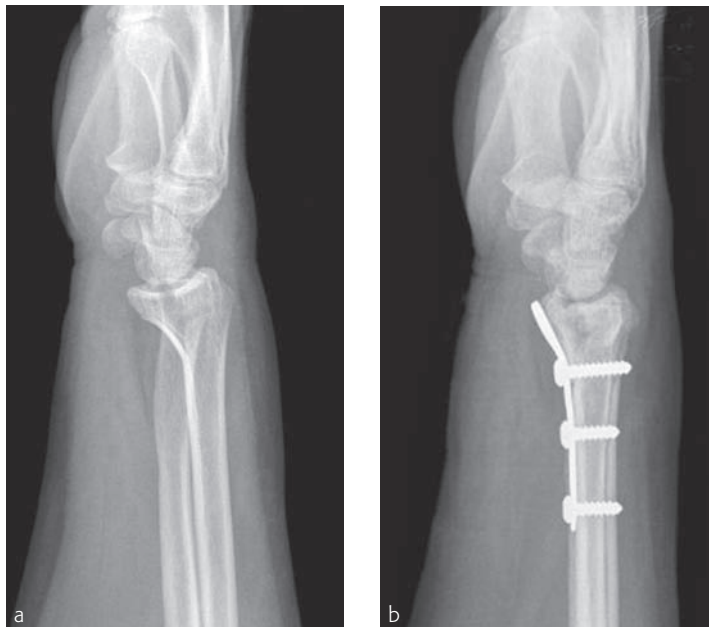
- This is a simple intraarticular fracture with volar displacement, which may be difficult to reduce and hold in an anatomically acceptable position by closed manipulation and splinting.
- The volar fracture fragment usually requires open reduction and can then be fixed by a simple buttress plate.
- The clinical results of accurately reduced and fixed fractures of this type are good.

Fig 3.8.1-1a–b
a   Preoperative x-ray: displaced partial articular fracture of distal radius with volar displacement.
b   Postoperative x-ray: stabilization with T-plate 3.5.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instrument set 3.5
- T-plates 3.5, right-angled, and screws 3.5/4.0 mm
- General small orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Standard operating table with radiolucent hand table
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Place the patient supine on an operating table with an attached radiolucent hand table. Abduct the injured arm, 80–90°, so that the hand and wrist lie in the center of the hand table (Fig 3.8.1-2).
- Take care to avoid traction on the brachial plexus by not over abducting or extending the arm at the shoulder. To prevent this, the hand table must be at the same level as the operating table.
- Apply a well fitting tourniquet cuff on the upper arm. Use of this is at the surgeon's discretion.
- Arrange the image intensifier so it can be brought over the wrist, avoiding the instrument trolleys and the table supports.

Fig 3.8.1-2

Author   Martin Wood
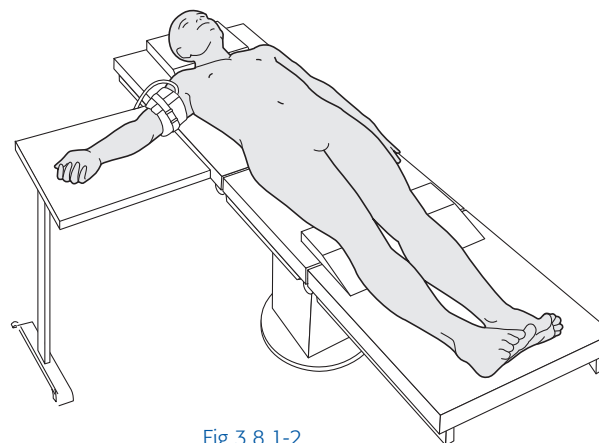
5   Skin disinfecting and draping

- The arm can be exsanguinated before draping. If a long procedure is anticipated, more tourniquet time can be gained by not inflating it until after the limb has been draped.
- Disinfect the arm and hand with the appropriate antiseptic to above the elbow (Fig 3.8.1-3a).
- Place a single drape over the hand table, followed by a larger drape on top which is wrapped around the limb as a shut off. Spread a third large drape over the patient's body, with the free edge wrapped around the injured limb, to seal off the arm (Fig 3.8.1-3b).

- Drape the image intensifier. The image intensifier end (x-ray tube) will go underneath the hand table and does not need to be covered.
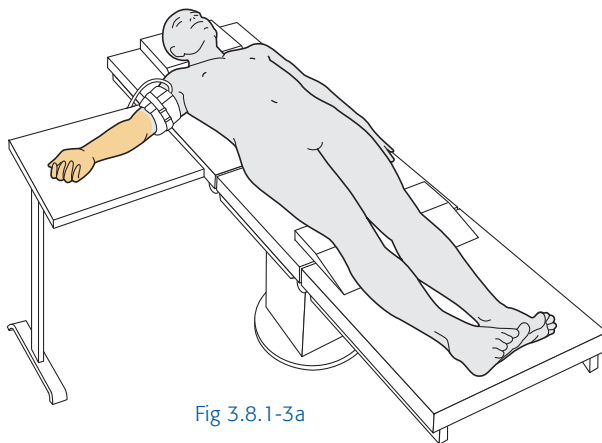
Fig 3.8.1-3a
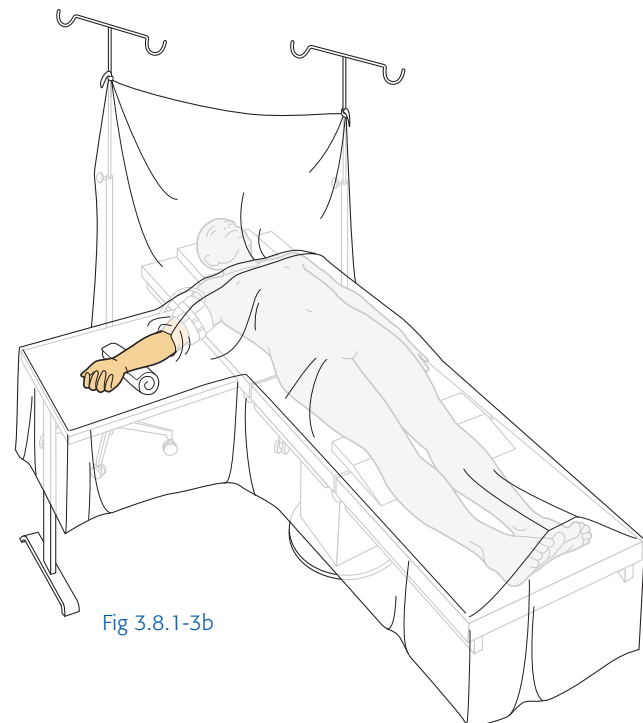
Fig 3.8.1-3b

6   Operating room set-up

- The surgeon sits next to the patient's trunk.
- The assistant sits on the opposite side of the hand table.
- The ORP is positioned next to the assistant.
- Make sure the assistant and the scrub nurse do not impede the access of the image intensifier.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.8.1-4).

Fig 3.8.1-4

Author   Martin Wood
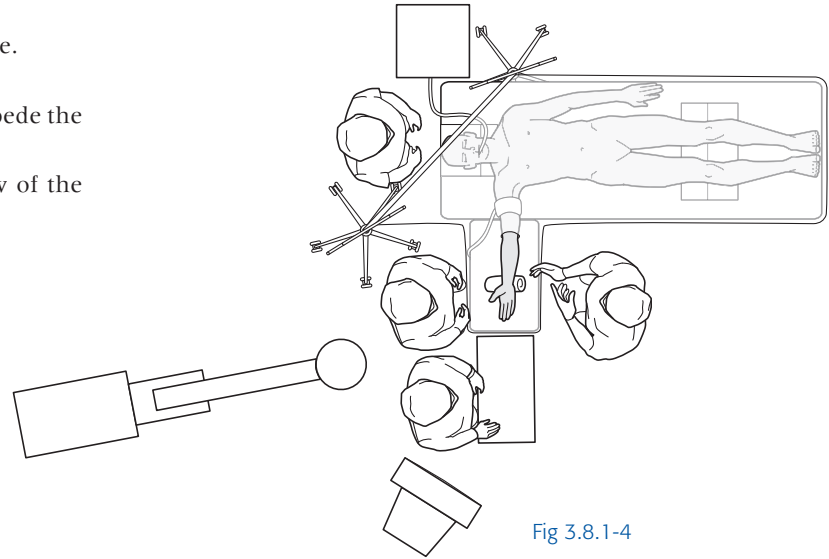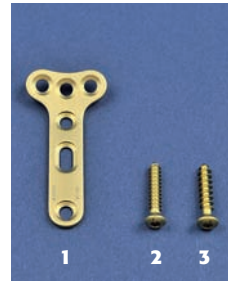
7   Instrumentation

Fig 3.8.1-5a   Implants
1.   T-plate 3.5, right-angled, 3 holes
2.   Cortex screw 3.5 mm
3.   Cancellous bone screw 4.0 mm
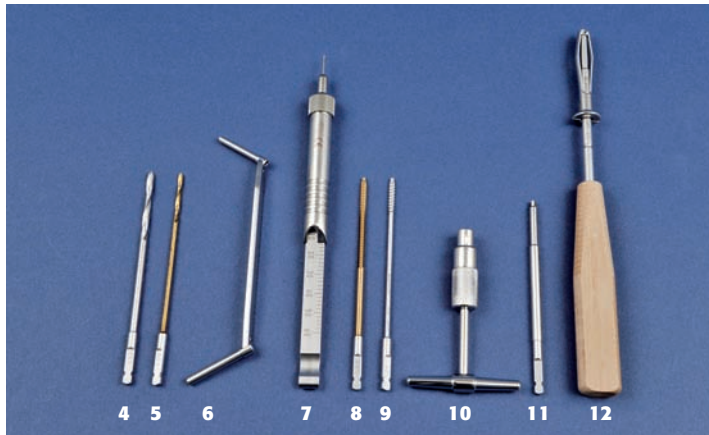
Fig 3.8.1-5b   Instruments for fracture fixation with T-plate 3.5
4.   Drill bit 3.5 mm
5.   Drill bit 2.5 mm
6.   Double drill sleeve 3.5/2.5 mm
7.   Depth gauge
8.   Tap 3.5 mm for cortex screw
9.   Tap 4.0 mm for cancellous bone screw
10.   T-handle
11.   Screwdriver shaft
12.   Screwdriver with holding sleeve

Fig 3.8.1-5c   Instruments for reduction and contouring
13.   Stagbeetle forceps, small
14.   Reduction forceps with points, small
15.   Bending pliers

8   Procedure and technique—step-by-step

- Make a 6 cm incision from the wrist crease, proximal, along the line of the flexor carpi radialis (FCR) tendon.
- Incise the bed of the FCR tendon and continue the dissection down to the bone of the anterior distal radius. Take the radial artery laterally and the tendon medially.
- Elevate the pronator quadratus muscle from the lateral edge of the radius with a periosteal elevator to expose the bone (Fig 3.8.1-6a).
- Open the fracture site carefully and clean out debris and hematoma. Longitudinal traction on the forearm and digital pressure on the fracture fragment usually reduces the fracture.

- The T-plate is used as a buttress plate to support the displaced volar fragment. It should therefore be undercontoured to provide maximal support. The plate is already preshaped and further bending is rarely required. The T fits over the fracture fragment holding it reduced.
- Ensure the plate is correctly placed with respect to the wrist joint and that it is correctly aligned along the long axis of the radius.
- Insert the first 3.5 mm cortex screw through the oval hole into the radial metaphysis (Fig 3.8.1-6b).
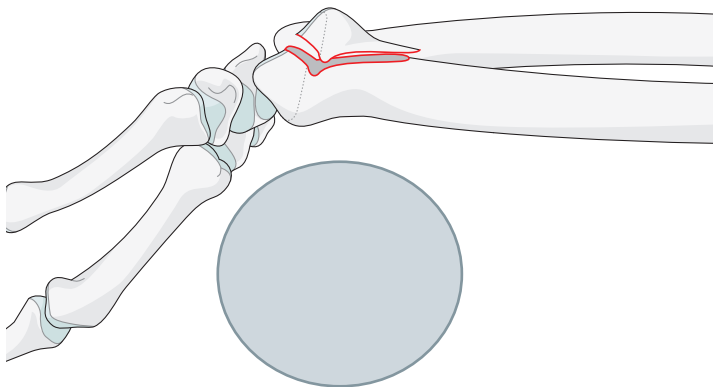
Fig 3.8.1-6a

Fig 3.8.1-6b

Author   Martin Wood
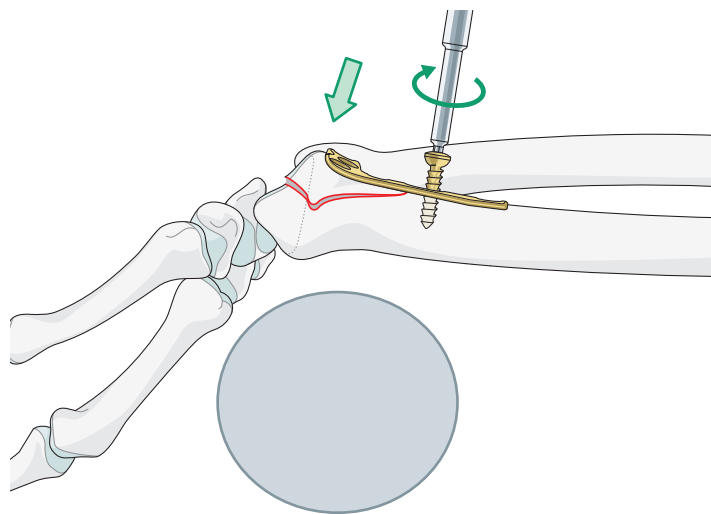
- Drill a 2.5 mm hole through both cortices, measure the length, tap it with the corresponding (gold-colored) tap, and insert the appropriate 3.5 mm cortex screw.
- Adjust the final position of the plate as the screw is tightened. This will reduce the fracture fragment against the intact dorsal cortex (Fig 3.8.1-6c).
- Check the position of the plate and the reduction in both planes with the image intensifier.
- Having achieved a satisfactory reduction and plate position, insert a second cortex screw through the plate into the radial shaft.
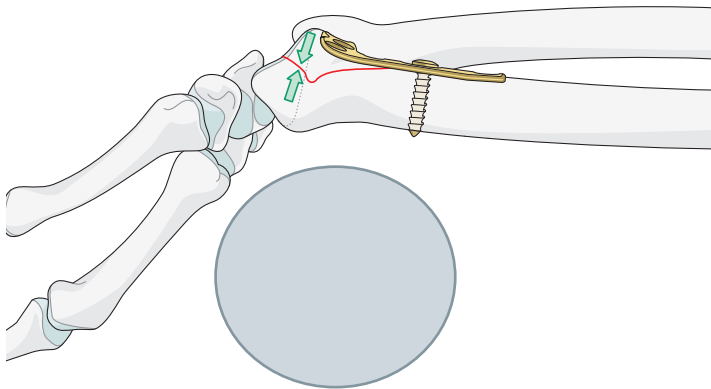
- Insert another 3.5 mm cortical bone screw into the proximal fragment to prevent lateral displacement.
- Cancellous bone screws may be inserted into the distal fragment. Drill a 2.5 mm pilot hole, measure the length, tap with the corresponding tap (silver), and insert the appropriate 4.0 mm cancellous bone screw. These screws are not always required and are used at the surgeon's discretion (Fig 3.8.1-6d).
- Take and save copies of final x-rays in both planes.
- Close the wound.
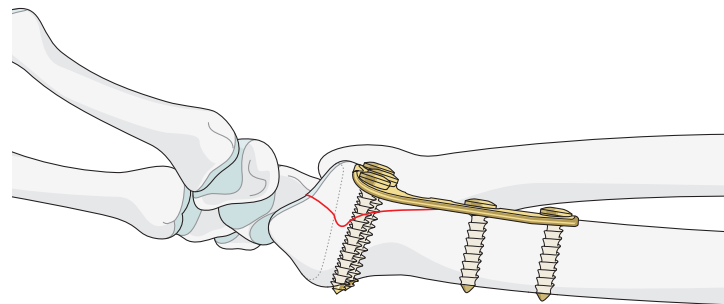
Fig 3.8.1-6c

Fig 3.8.1-6d

9 Specific perioperative care

- Take care when positioning the patient's arm to avoid traction of the nerves in the neck and the brachial plexus.
- Preliminary closed reduction of the fracture can help to disimpact fragments and make operative reduction easier.

10 Specific postoperative care

- Take postoperative x-rays to check and document the reduction and position of the implant unless adequate images have been saved from the image intensifier.
- Start gentle mobilization after 48 hours.
- Observe the limb for signs of median nerve compression, and if these persist: urgent carpal tunnel decompression must be considered.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of required small fragment T-plates are available.
- Be prepared to use another T-plate than that planned, such as an LCP version or plates of smaller dimensions.

- If an oblique LCP T-plate is chosen, and not the preplanned conventional right-angled T-plate, note that the specific right or left version has to be selected.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Having achieved reduction in the lateral plane, it is important to check with the image intensifier in the AP plane that the distal fragment is not still displaced radially.
- Make sure that if screws have been inserted into the distal fragment they have not penetrated the joint. Check for crepitus upon moving the joint, which means screws may have entered the joint. Screw penetration is not easy to assess radiographically.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Martin Wood

3.8.2   Complex distal radial fracture (23-C2): stabilization with small external fixator

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Surgical management

- Stabilization with small external fixator

Alternative implant

- Open reduction and fixation with distal radius plate 3.5 or 2.4

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1   Introduction
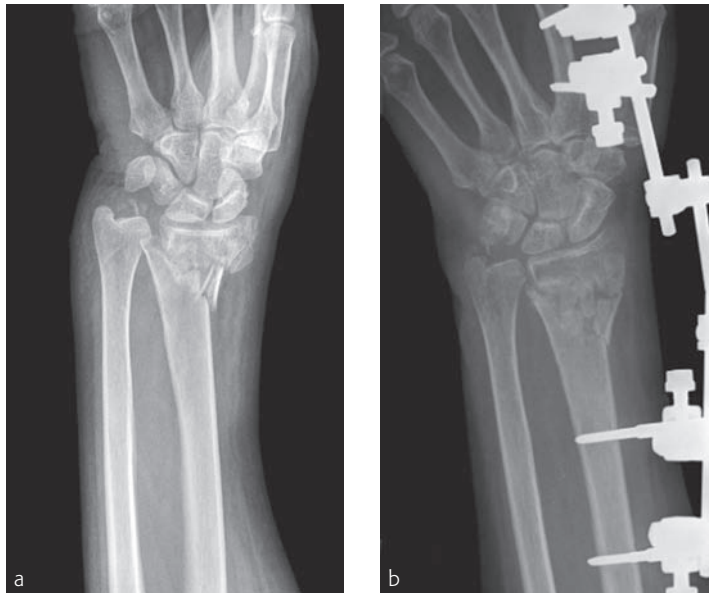
Fig. 3.8.2-1a–b
a   Preoperative x-ray: complex multifragmentary intraarticular distal radial fracture.
b   Postoperative x-ray: stabilization with small external fixator.

- Indications for an external fixator are:
  - Soft-tissue conditions that preclude open reduction and internal fixation
  - Fracture configurations that are too complex to achieve accurate open reduction and plate fixation

- Techniques of applications:
  - When applied in a joint-bridging fashion, two pins are inserted into the metacarpal of the index finger and two into the shaft of the radius proximal to the fracture.
  - When applied in a nonjoint-bridging construct, two pins are inserted into the unfragmented distal radial fragment and two in the radial shaft. This allows for early wrist movement.
  - The external fixator can be supplemented by percutaneous K-wires or screws used to stabilize individual fracture fragments.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small external fixator set with 3.0 and 4.0 mm Schanz screws
- Set of K-wires 1.2–1.6 mm
- General small orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Standard operating table with radiolucent hand table
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional, very rarely inflated)

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- Place the patient supine on the operating table with an attached radiolucent hand table. Abduct the injured arm, 80–90º, so that the hand and wrist lie at the center of the hand table (Fig 3.8.2-2).
- Take care to avoid traction on the brachial plexus by not over abducting or extending the arm at the shoulder. To prevent this, the hand table must be at the same level as the operating table.
- Apply a well fitting tourniquet cuff on the upper arm. Inflate only if needed.
- Arrange the image intensifier so it can be brought over the wrist, avoiding the instrument trolleys and the table supports.

Fig 3.8.2-2

Author   Martin Wood
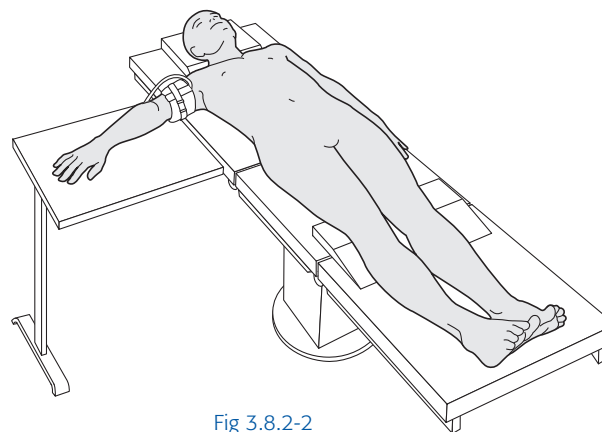
5   Skin disinfecting and draping

- Disinfect the arm and hand with the appropriate antiseptic to above the elbow (Fig 3.8.2-3a).
- Place a single drape over the hand table, followed by a larger drape on top which is wrapped around the limb as a shut off. Spread a third large drape over the patient's body, with the free edge wrapped around the injured limb, to seal off the arm (Fig 3.8.2-3b).

- Drape the image intensifier. The image intensifier end (x-ray tube) will go underneath the hand table and does not need to be covered.
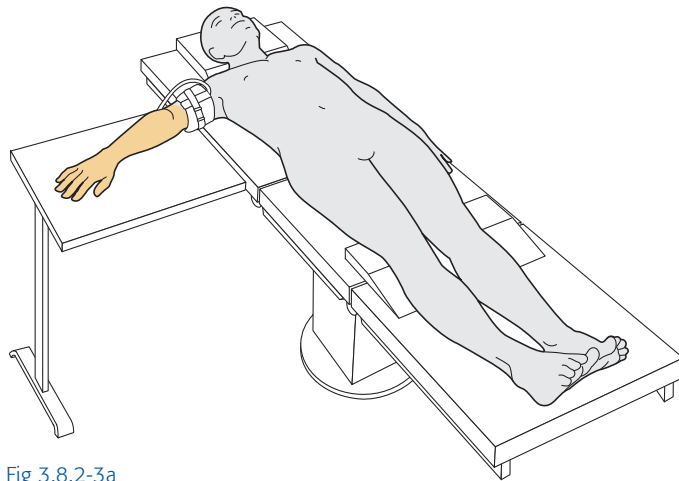
Fig 3.8.2-3a
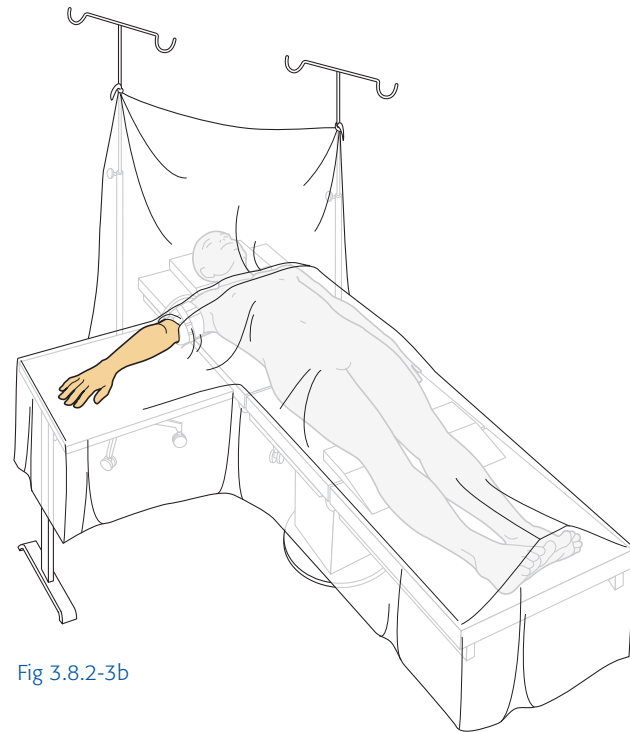
Fig 3.8.2-3b

6 Operating room set-up

- The surgeon sits next to the patient's trunk.
- The assistant sits on the opposite side of the hand table.
- The ORP is positioned next to the assistant.
- Make sure the assistant and scrub nurse do not impede the access of the image intensifier.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.8.2-4).
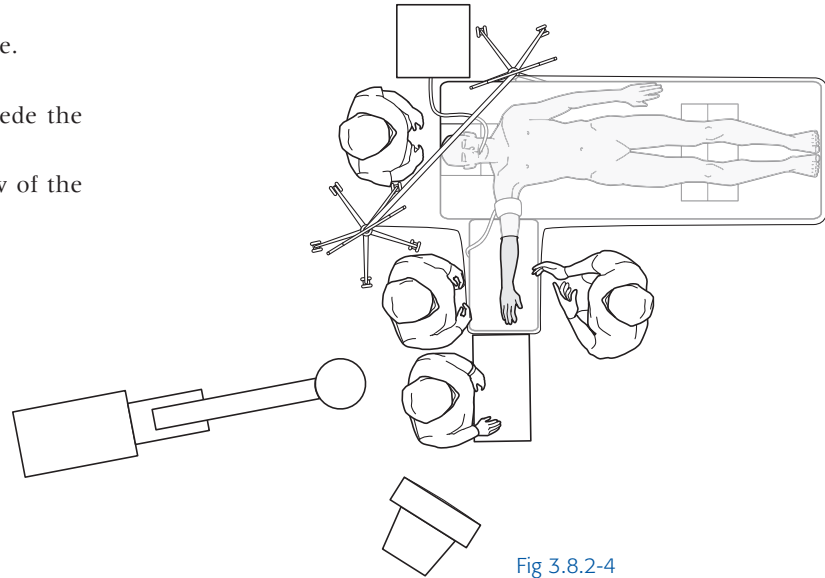
Fig 3.8.2-4

7   Instrumentation
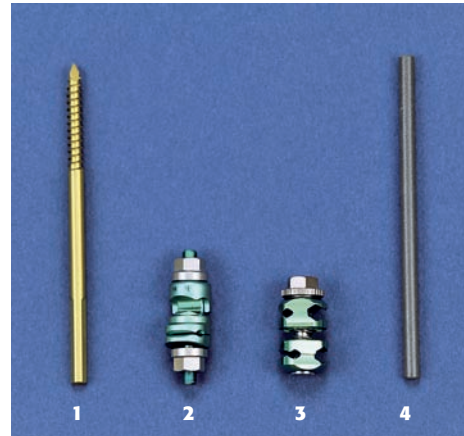
Fig 3.8.2-5a   Implants
1.   Schanz screw 4.0 mm
2.   Self-holding clamp 1.8–4.0 mm
3.   Self-holding combination clamp 2.5–4.0 mm
4.   Carbon fiber rod 4.0 mm
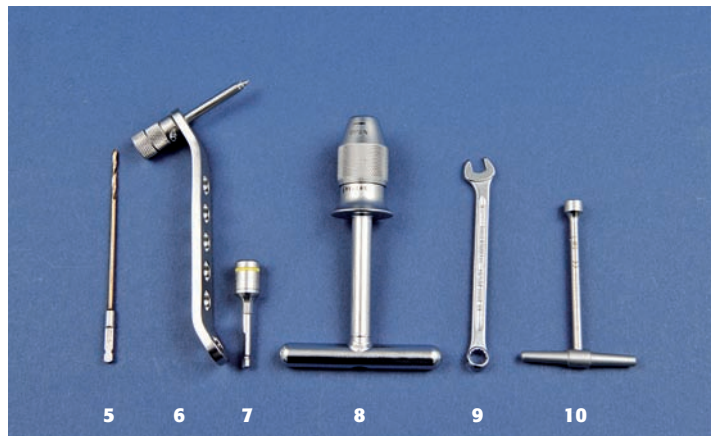
Fig 3.8.2-5b   Instruments for fracture fixation with external fixator
5.   Drill bit 2.5 mm
6.   Triple drill sleeve assembly (drill sleeve 4.0 mm,
       drill sleeve 4.0/2.5 mm, trocar 2.5 mm, and handle)
7.   Adapter for Schanz screws 4.0 mm
8.   Universal chuck with T-handle, small
9.   Combination wrench 7 mm
10.   Socket wrench 7 mm

8 Procedure and technique—step-by-step

- Reduce the fracture under the guidance of the image intensifier.
- Insert K-wires if necessary to align and hold the fracture fragments.
- Identify the site for the insertion of each Schanz screw using the image intensifier and mark it on the skin with a skin marker.
- Use 4.0 or 3.0 mm Seldrill Schanz screws depending on the size of the bone.
- Insert the Schanz screws in the metacarpal as far apart from each other as possible, but so as to engage in the cortex rather than the metaphysis.
- Make stab incisions over the metacarpal of the index finger. Flex the finger at the metacarpophalangeal joint during drilling and screw insertion to move the digital nerves volar-ward away from the Schanz screw insertion site. Deepen it to the bone with blunt dissection.
- Aim to insert both Schanz screws at an angle between 40° and 60° to vertical in the metacarpal and radius (Fig 3.8.2-6a).

- Use the drill sleeve assembly with the trocar and palpate each edge of the bone to find its center.
- Position the drill sleeve assembly centrally over the bone and withdraw the trocar to insert the Seldrill Schanz screw mounted on a drill with the corresponding adapter.
- Make sure the Seldrill Schanz screw penetrates the near cortex and comes to rest with its tip against the far cortex. This can be difficult to judge when using a power drill, therefore it is safer to make the last few turns by hand using the small universal chuck with T-handle (Fig 3.8.2-6b).
- If conventional Schanz screws are used, the bone must be predrilled through both cortices after removal of the trocar from the drill sleeve assembly using a 2.5 mm drill bit for the 4 mm Schanz screw or a 2.0 mm drill bit for the 3 mm screws.
- Remove the drill bit and insert the Schanz screw. Make certain that the screw is inserted far enough to engage the opposite cortex.
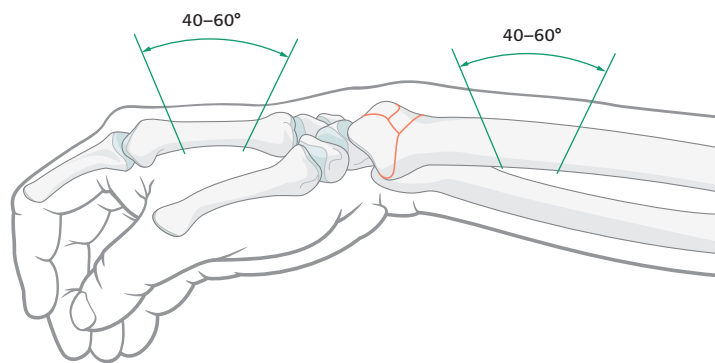
Fig 3.8.2-6a

Fig 3.8.2-6b

Author   Martin Wood
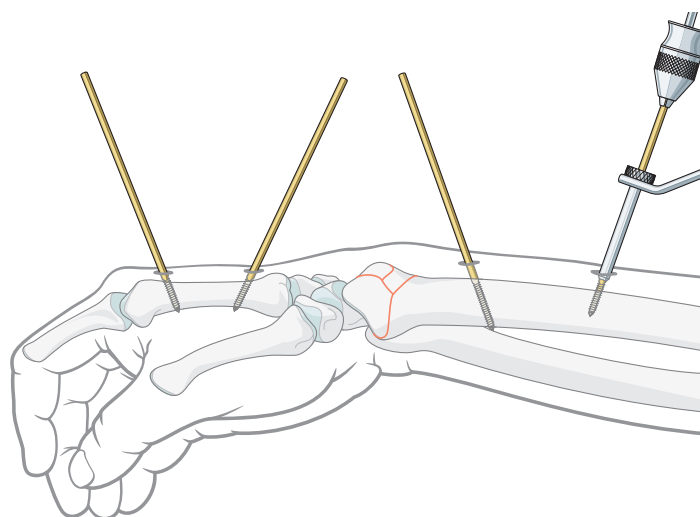
- In the radius the distal Schanz screw should be inserted through healthy soft tissue just proximal to the fracture and the second one 5–6 cm more proximally.
- Make a stab incision over the shaft of the radius at the site of each Seldrill Schanz screw insertion point. Use blunt dissection to reach the bone and avoid damage to the superficial radial nerve which is very close to the dissection.
- Expose the bone adequately and position the drill sleeve assembly before inserting the 4 mm Seldrill Schanz screws, applying the same technique used in the metacarpal.
- Check the correct positioning of all Schanz screws with the image intensifier.
- Mount two self-holding clamps to a carbon fiber rod and attach them to each pair of Schanz screws in the metacarpal and the radius. Tighten all nuts firmly with the combination wrench 7 mm (Fig 3.8.2-6c).
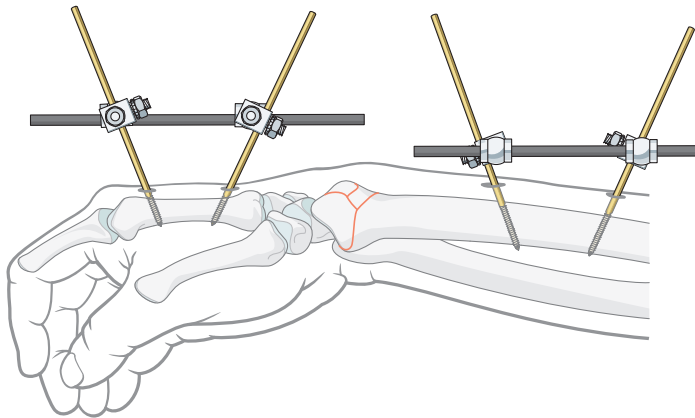
- Attach a third short carbon fiber rod with two self-holding combination clamps to the ends of the already applied rods nearest to the fracture (Fig 3.8.2-6d). The clamps are left loose.
- Carry out final reduction manipulation under the guidance of the image intensifier and tighten the nuts of the combination clamps.
- Take and save copies of final x-rays in both planes.
- For extra stability an additional long neutralization rod may be attached directly between a radius Schanz screw and a metacarpal Schanz screw.
- Ensure there is adequate release of the skin around each screw site.
- Close the skin incisions over the radius.
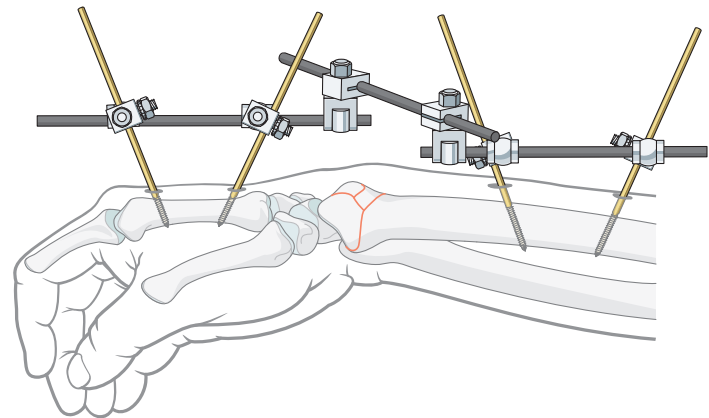
Further information is available on AO Teaching video 22045: Multifragmental Fracture—Distal Radius—Distal Radius Fixator.

Fig 3.8.2-6c

Fig 3.8.2-6d

9 Specific perioperative points

- Take care when positioning the patient's arm to avoid traction of the nerves in the neck and brachial plexus.
- Excessive traction across the wrist should be avoided as this can lead to stiffness and increases the risk of postoperative complex regional pain syndrome.
- An x-ray taken after application of the fixator should not show an increase in the size of the joint space, as this would mean that too much traction has been applied.
- Place the clamps and the connecting rods in such a way to allow AP and lateral x-ray images of the fracture.

10 Postoperative care

- Take postoperative x-rays to check and document the reduction and position of the external fixator, unless adequate images have been saved from the image intensifier.
- Clean and dress the Schanz screw sites daily. Once clean and dry, no further dressings are needed.
- Remove the external fixator between 4 and 6 weeks after surgery, depending on healing of the fracture.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Ensure that adequate numbers of clamps and rods of different length are available before starting.
- Be aware of the difference between Seldrill Schanz screws which are self-drilling and conventional Schanz screws which require predrilling, with a 2.5 mm drill bit for the 4 mm Schanz screws and 2.0 mm drill bit for the 3 mm Schanz screw.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Make sure the Schanz screws are inserted across the center of the bones, engaging both cortices to guarantee maximum purchase in the bone. The Seldrill Schanz screws are designed to engage the far cortex with the sharp tip but should not penetrate it.
- Do not put too much traction on the wrist ligaments in an attempt to reduce the fracture. This does not work, is painful, can cause long-term damage to the ligaments, and increases the risk of the patient developing complex regional pain syndrome.
- Try and leave the wrist in a neutral position once the external fixator has been applied. This is more functional, particularly if the wrist becomes stiff.
- Ensure that the incisions are adequately released around each Schanz screw site to prevent skin tension and irritation.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Martin Wood

3.8.3   Complex distal radial fracture (23-C3): stabilization with LCP distal radius plate 2.4 and straight radial buttress plate 2.4

Surgical management

- Stabilization with LCP distal radius plate 2.4 and straight radial buttress plate 2.4

Alternative implants

- External fixator
- LCP distal radius plate 2.4 without straight radial buttress plate 2.4
- Dorsal LCP L- or T-shaped distal radius plates 2.4
- Volar column LCP 2.4 with or without straight radial buttress plate 2.4
- Percutaneous K-wire fixation

1   Introduction
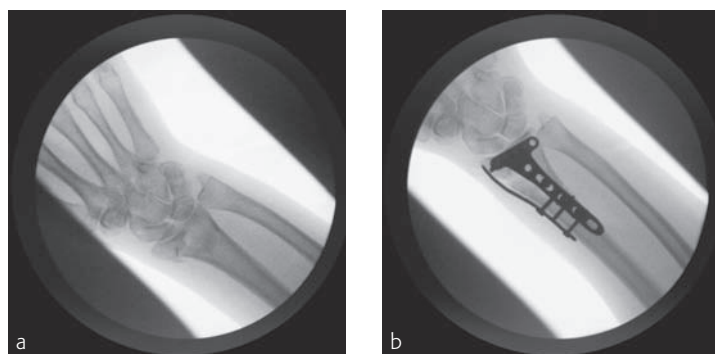
Fig 3.8.3-1a–b
a   Preoperative x-ray: complex multifragmentary intraarticular distal radial fracture.
b   Postoperative x-ray: stabilization with LCP distal radius plate 2.4 and straight radial buttress plate 2.4.

- Complex C3 fractures usually require fixation, as an acceptable position can rarely be achieved and held accurately by manipulation and a plaster cast.
- There is often a displaced radial styloid fragment which can be stabilized with a radial buttress plate.
- The carpus tends to displace in a radial direction with the styloid fragment.
- If the joint surface is not accurately reduced, posttraumatic arthritis can develop particularly in younger patients.
- There is currently little evidence that in the long term plate fixation provides a better result than reduction and fixation with percutaneous K-wires.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Locking distal radius system set with instruments and implants
- General small orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Standard operating table with radiolucent hand table
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- Place the patient supine on an operating table with an attached radiolucent hand table. Abduct the injured arm, 80–90°, so that the hand and wrist lie at the center of the hand table (Fig 3.8.3-2).
- Take care to avoid traction on the brachial plexus by not over abducting or extending the arm at the shoulder. To prevent this, the hand table must be at the same level as the operating table.
- Apply a well fitting tourniquet cuff on the upper arm. Inflation is at the surgeon's discretion.
- Arrange the image intensifier so it can be brought over the wrist, avoiding the instrument trolleys and the table supports.

Fig 3.8.3-2

Author   Martin Wood
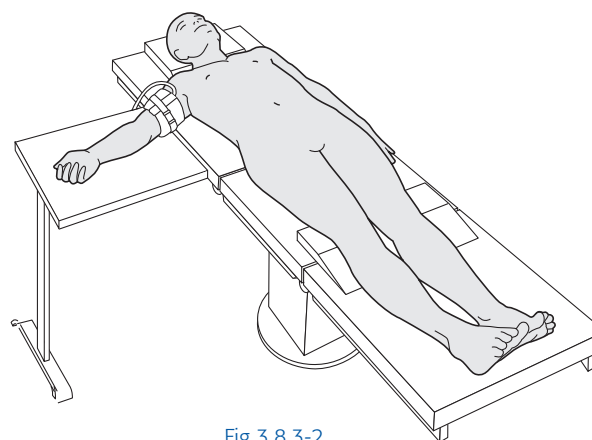
5   Skin disinfecting and draping

- The arm can be exsanguinated before draping. If a long procedure is anticipated, more tourniquet time can be gained by not inflating it until after the limb has been draped.
- Disinfect the arm and hand with the appropriate antiseptic to above the elbow (Fig 3.8.3-3a).
- Place a single drape over the hand table, followed by a larger drape on top which is wrapped around the limb as a shut off. Spread a third large drape over the patient's body, with the free edge wrapped around the injured limb, to seal off the arm (Fig 3.8.3-3b).

- Drape the image intensifier. The image intensifier end (x-ray tube) will go underneath the hand table and does not need to be covered.
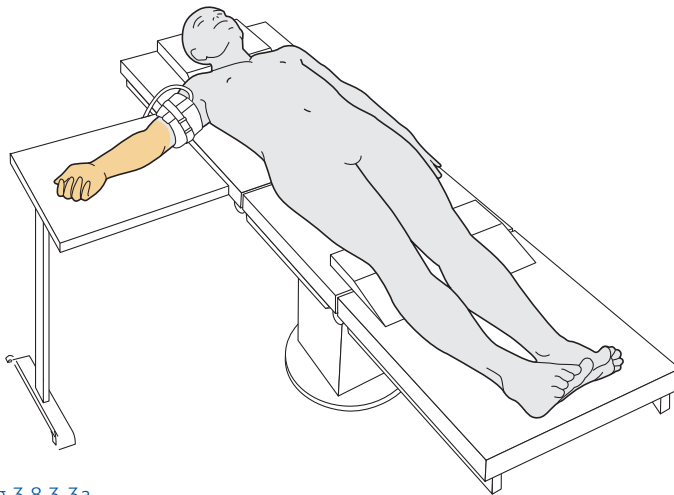
Fig 3.8.3-3a
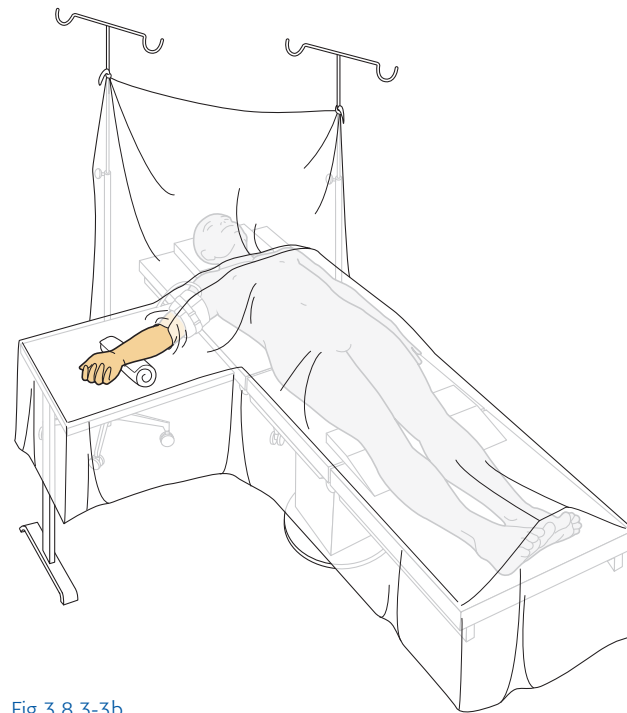
Fig 3.8.3-3b

6 Operating room set-up

- The surgeon sits next to the patient's trunk.
- The assistant sits on the opposite side of the hand table.
- The ORP is positioned next to the assistant.
- Make sure the assistant and scrub nurse do not impede the access of the image intensifier.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.8.3-4).

Fig 3.8.3-4

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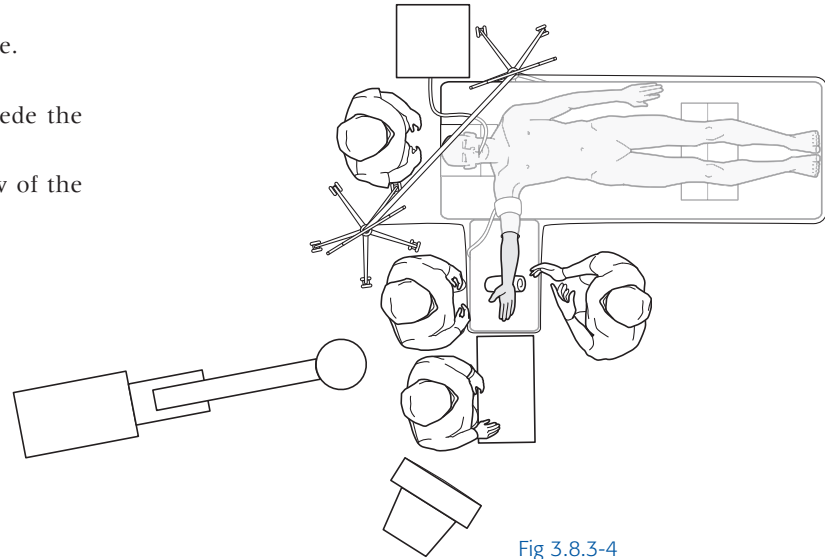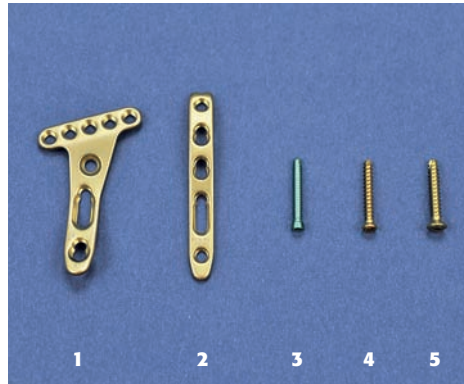
Fig 3.8.3-5a   Implants (right)
1.   LCP distal radius plate 2.4 mm, 5 holes
2.   LCP distal radius plate 2.4 mm, straight, 5 holes
3.   Locking head screw 2.4 mm
4.   Cortex screw 2.4 mm
5.   Cortex screw 2.7 mm
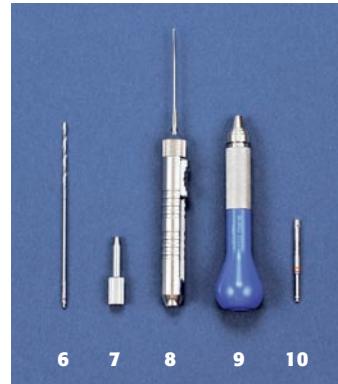
Fig 3.8.3-5b   Instruments for fracture fixation with radius plate 2.4 mm and LHS 2.4 mm
6.   Drill bit 1.8 mm
7.   LCP drill sleeve 1.8 mm
8.   Depth gauge
9.   Handle with mini quick coupling
10.   Screwdriver shaft, self-holding
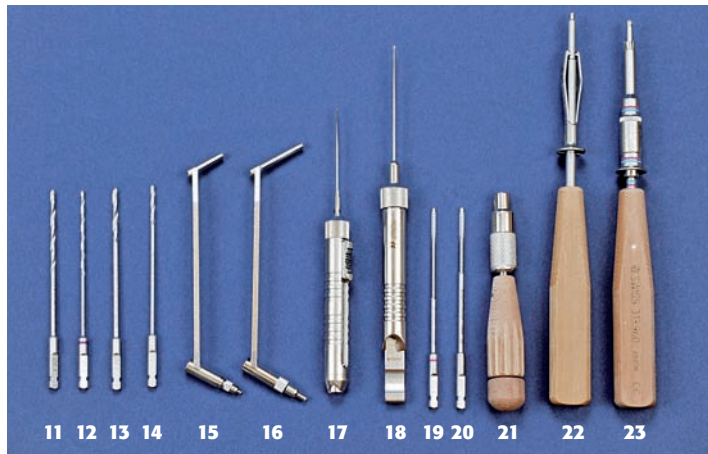
Fig 3.8.3-5c   Instruments for fracture fixation with radius plate 2.4 mm and cortex screws 2.4–2.7 mm
11.   Drill bit 2.4 mm
12.   Drill bit 1.8 mm
13.   Drill bit 2.7 mm
14.   Drill bit 2.0 mm
15.   Universal drill sleeve 2.4 mm
16.   Universal drill sleeve 2.7 mm
17.   Depth gauge for screws 2.4 mm
18.   Depth gauge for screws 2.7 mm
19.   Tap 2.4 mm
20.   Tap 2.7 mm
21.   Handle with quick coupling
22.   Screwdriver and holding sleeve for screws 2.7 mm
23.   Screwdriver and holding sleeve for screws 2.4 mm

Fig 3.8.3-5d   Instruments for reduction and contouring
24.   Reduction forceps with points, small
25.   Stagbeetle forceps, small
26.   Pliers for distal radius plates 1.0–2.4 mm

385

8 Procedure and technique—step-by-step

- Make a 6 cm incision from the wrist crease, proximal, along the line of the flexor carpi radialis (FCR) tendon.
- Incise the bed of the FCR tendon and continue dissection to the bone. Hold the radial artery laterally and the tendon medially. Elevate the exposed pronator quadratus muscle from the lateral edge of the radius to expose the bone.
- Open the fracture site carefully and wash out debris and hematoma.
- Apply longitudinal traction and digital pressure to reduce the fracture. Intraarticular fracture fragments need to be anatomically reduced. Depressed fragments will need elevation. Precise preoperative imaging often using CT scans allows planning of this complex procedure.
- Stabilize the fracture fragments temporarily with percutaneously inserted K-wires.
- Place an LCP distal radius plate 2.4 on the bone. Contouring the plate to fit the bone may be needed (Fig 3.8.3-6a). Respect the scored underside of the plate during contouring.

- The plate comes in left and right versions, be sure to use the correct-sided implant.
- First insert a 2.7 mm cortex screw through the oval hole into the metaphysis. Predrill with a 2 mm drill bit using the universal drill sleeve, measure the length, and select and insert the appropriate screw. Since all screws on this set are self-tapping there is no need to use a tap. Adjust the position of the plate as the screw is tightened (Fig 3.8.3-6b).
- Check the position of the plate and the reduction with the image intensifier in both planes before any further screws are inserted.
- Insert a second 2.7 mm cortex screw or a 2.4 mm locking head screw into the radial shaft once satisfactory reduction has been achieved (Fig 3.8.3-6c). In poor-quality bone more than one locking head screw in the shaft of the radius will be required.
- Insert 2.4 mm locking head screws into the distal fragments to prevent fracture displacement.
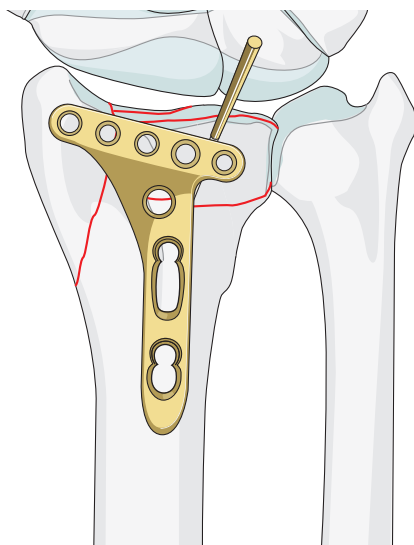
Fig 3.8.3-6a
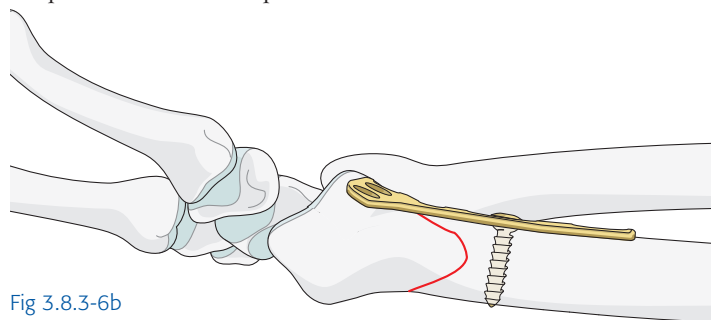
Fig 3.8.3-6b

Fig 3.8.3-6c

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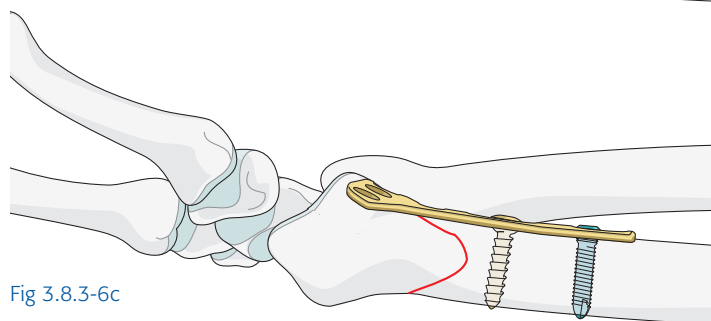
- Predrill the pilot holes for the 2.4 mm locking head screws with the 1.8 mm drill bit using the LCP drill sleeve. Read the screw length directly from the scale of the drill bit. Insert the appropriate self-tapping LHS 2.4 mm. The number and placement of the screws depend on the fracture pattern.
- Apply a radial buttress plate to the radial styloid if this separate fragment is not held adequately with the volar plate. This plate should be applied before any screws are placed in the distal fragment.
- Fix the styloid fragment initially with an oblique K-wire placed through the tip of the radial styloid. There is a notch in the end of the radial buttress plate to allow it to be pushed up against the wire.
- Insert the radial buttress plate through a separate incision over the dorsoradial aspect of the wrist and expose the bone between the first and second extensor compartments.

- Use a 2.4 mm self-tapping cortex screw (1.8 mm pilot drill hole) to press the plate to the radial shaft proximally, thereby buttressing the distal fragment (Fig 3.8.3-6d).
- Check the reduction in both planes with an image intensifier.
- Insert additional 2.4 mm cortex or locking head screws through the plate into the radial shaft. In poor-quality bone more than one LHS in the shaft of the radius may be required.
- Insert further locking head screws into the distal fracture fragments through both plates to maintain stability as needed (Fig 3.8.3-6e).
- Remove any temporary K-wires.
- Take and save copies of final x-rays in both planes.
- Close the wounds.

Further information is available on AO Teaching video 22060: Distal Radius Fracture—2.4 LCP Palmar Plating for Reversed Barton and Colles Type Fracture.
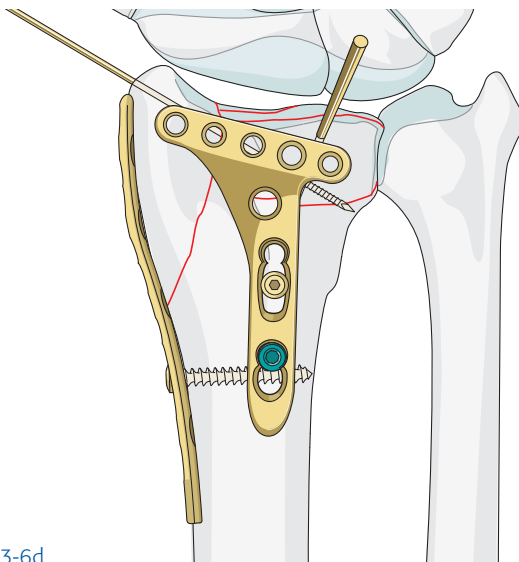
Fig 3.8.3-6d
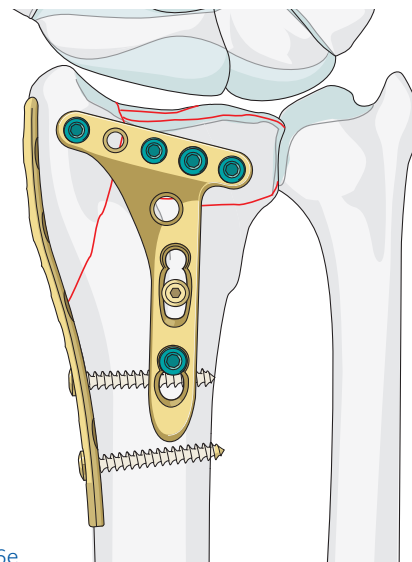
Fig 3.8.3-6e

9   Specific perioperative care

- Take care in positioning the patient to avoid traction of the nerves in the neck.
- Preliminary closed reduction of the fracture can help to disimpact fragments and make operative reduction easier.
- Longitudinal traction applied using Chinese finger traps can be useful to maintain reduction.

10   Specific postoperative care

- Take postoperative x-rays to check and document reduction and position of the implant unless adequate images have been saved from the image intensifier.
- Start gentle mobilization once the dressing is removed after 48 hours.
- Observe the limb carefully for signs of median nerve compression. If symptoms persist, then urgent carpal tunnel decompression must be considered.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of plates and screws are available.
- Note that there are specific left and right versions of the volar locking plates.
- Note that the T part of the distal radius plate can only accommodate 2.4 mm LHS.
- Note that the shaft part of the distal radius plate can accommodate both LHS and conventional 2.4 or 2.7 mm cortex screws.

- Note that the radial styloid buttress plate only accommodates the 2.4 mm dimension of both screws.
- Make sure to use the correct drill bit size:
  - 1.8 mm drill bit for 2.4 mm screws
  - 2.0 mm drill bit for 2.7 mm screws
- Note that all screws are self-tapping.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Having achieved reduction in the lateral plane, it is important to check with the image intensifier in the AP plane that the distal fragment is not still displaced radially.

- Check the position of the radiocarpal joint by careful palpation with a needle.
- Do not open the joint from the volar aspect, as this can lead to wrist instability.
- Be sure to use the correct screw and drill combinations in the appropriate holes.

Author   Martin Wood

- Take care that screws inserted into the distal fragment do not penetrate the joint.
- Check for crepitus when moving the wrist to ascertain that no screw has entered the joint.

- Due to the slope of the radius it can be difficult to see on x-ray if screws have penetrated the wrist joint. A lateral view at 20° oblique to the wrist will demonstrate the joint surface with less bone overlap than a standard lateral view (Fig 3.8.3-7a–c).
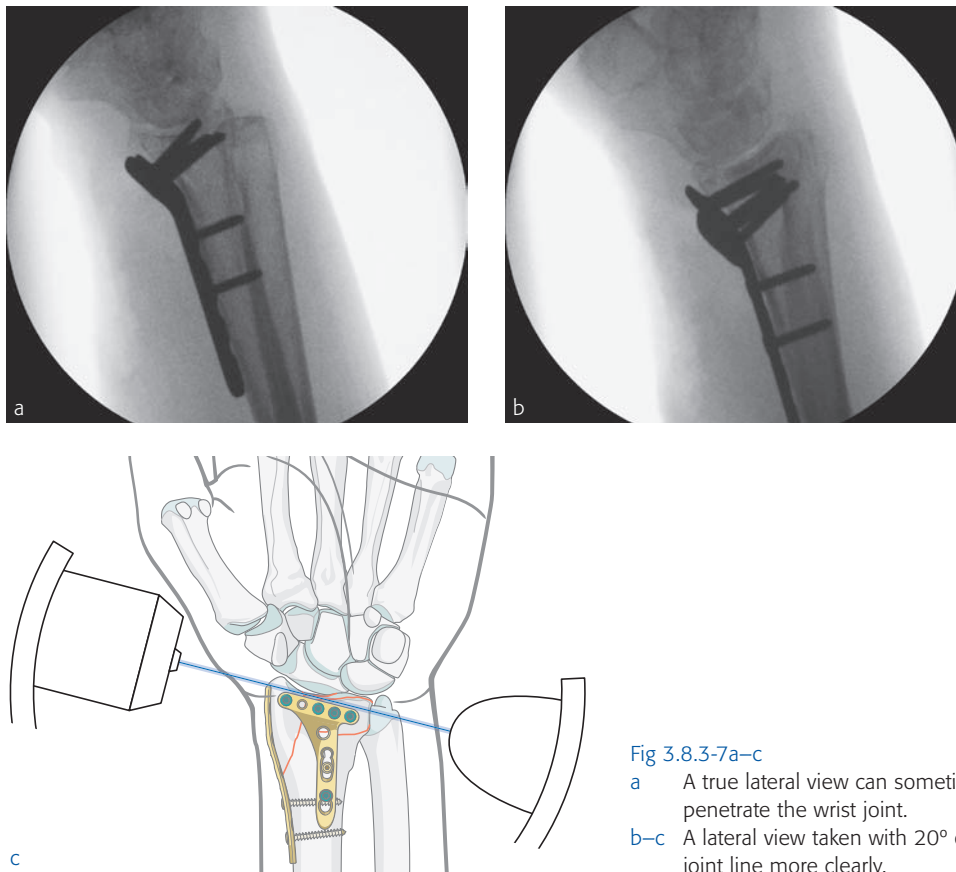
Fig 3.8.3-7a–c
a   A true lateral view can sometimes show screws in the radial styloid appearing to penetrate the wrist joint.
b–c A lateral view taken with 20° of angulation in the line of the distal radius shows the joint line more clearly.

3.9 Hand fractures

Author   Doug Campbell

3.9   Hand fractures

Implants and surgical technique

- Compact hand LC-DCP 2.0
- Headless compression screw (HCS) 3.0 mm
- Cortex screw 1.5 mm (lag screw technique)

Cases

- Metacarpal shaft fracture
- Undisplaced scaphoid waist fracture
- Condylar phalangeal fracture

Introduction

- Hand fractures present a particular challenge because of the relative functional importance of the overlying soft tissues.
- Scar formation through a natural healing process delays rehabilitation and must be minimized by careful surgical technique, judicious fracture exposure, gentle handling, and prevention of drying of the soft tissues.
- Small bones require small implants, and accurate planning, placement, and insertion is vital in achieving stability.
- Surgical approaches must be performed through planes and areas which inflict the least damage to the gliding soft tissues.
- Simple swelling of a digit without fracture, laceration, or surgical exposure is sufficient to cause permanent stiffness of the small joints. Both injury and treatment will result in edema and stiffness which must be recognized and treated actively and aggressively by elevation, compression, and movement.
- Hand fracture patterns follow those of larger bones. Diaphyseal injuries can be transverse, oblique (long or short), spiral, or multifragmentary. Loss of alignment in rotation can result in the fingers 'crossing over' when fully flexed. Correcting rotational alignment is therefore a priority in managing hand fractures. Shortening of the bone can result in significant functional disturbance as the overlying muscles and tendons alter their tension.
- The need for early mobilization in an injured hand dictates that any operative treatment must achieve stable fixation, and be applied with a high degree of technical competency. Unlike other anatomical regions, it is not advisable to immobilize the hand until union is mature.
- If multiple structures in the hand are injured, the decision on how to manage the fractures will depend on which other structures are involved. For example, if a tendon repair is necessary, and that repair's rehabilitation demands movement, the skeletal repair must be stable enough at an early stage to permit rehabilitation of the tendon injury.

Müller AO/OTA Classification—hand fractures

78 Phalanges

77 Metacarpals

Carpals 75 (ulnar) and 75 (radial)
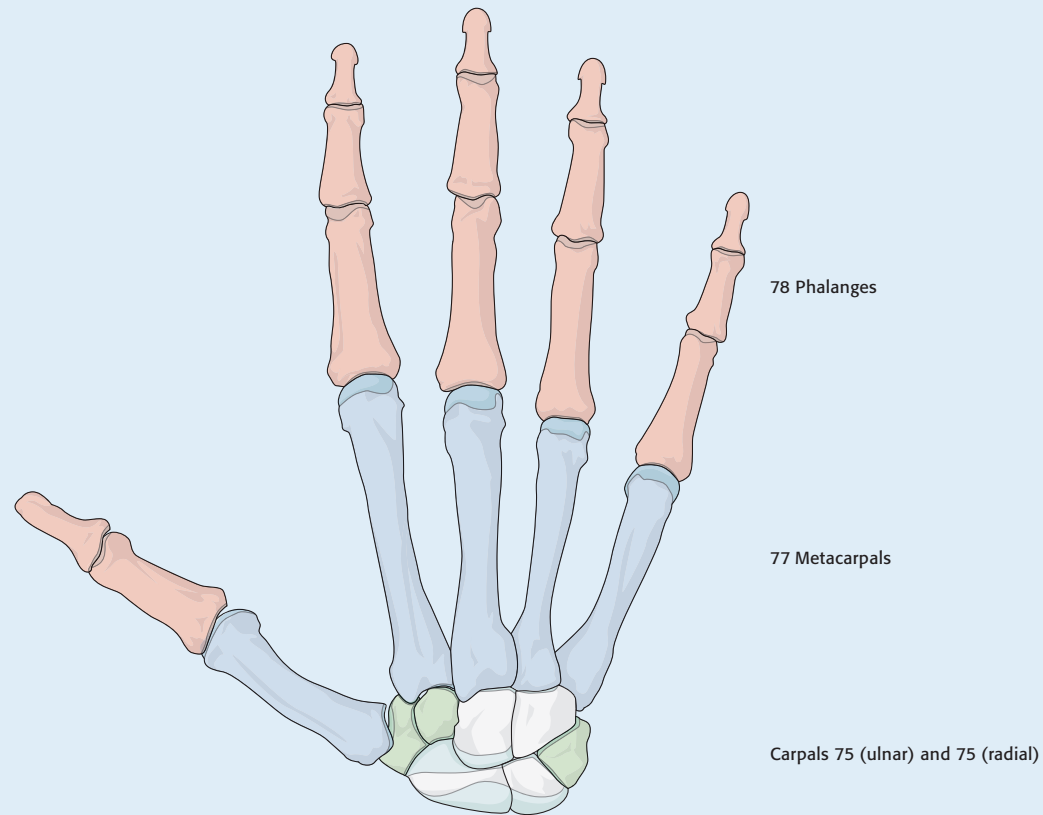
The Müller AO/OTA Classification of hand fractures is complex. The carpa bones are classified as 75 (ulnar carpal bones) and 76 (radial carpal bones), the metacarpals are 77, and the phalanges as 78.

Author   Doug Campbell

3.9.1   Metacarpal shaft fracture: stabilization with a dorsal compact hand LC-DCP 2.0

Surgical management

- Stabilization with dorsal compact hand LC-DCP 2.0

Alternative implants

- Compact hand LC-DCP 2.4 in large adult
- LCP 2.0

1   Introduction

Fig 3.9.1-1a–b
a   Preoperative x-ray: transverse fracture of shaft of fifth metacarpal.
b   Postoperative x-ray: stabilization with LC-DCP 2.0.

- Metacarpal fractures are common. The most common fracture pattern is the neck fracture. This rarely requires intervention. Shaft fractures are more likely to require reduction and stabilization because for a given angulation they produce more shortening than in a neck fracture. This can influence extensor tendon function.
- The stability of the hand is most affected when a border (index or small finger) metacarpal has sustained an unstable fracture.
- Adjacent fractures can be approached through a single incision placed between the affected metacarpals.
- A dorsally placed compression plate will act as a tension band only if the palmar cortex is not fragmented.
- The results of internal fixation are good if an early program of active movement is prescribed.
- Occasionally, the implant will require removal once the fracture has healed. This is less likely with modern implant design and surface finishes.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Compact hand set 2.0 mm
- 4-hole and 5-hole LC-DCP 2.0 mm
- General small orthopaedic instruments
- Micro drive or similar small compatible air or battery drill with attachments

Equipment:
- Standard operating table
- Large hand table
- Image intensifier (a small one is suitable if available)
- X-ray protection devices for personnel and patient
- Tourniquet with exsanguinator

3 Anesthesia

- This procedure is performed with the patient under regional (eg, axillary) or general anesthesia.

Author Doug Campbell

4 Patient and x-ray positioning

- Position the patient supine and if under regional anesthesia make him/her comfortable with pillows under the head and under the knees (Fig 3.9.1-2).
- The shoulder is only anesthetized by high block (interscalene or supraclavicular). Patients with coexistent shoulder pathology must be positioned carefully to avoid discomfort.
- Apply a well padded pneumatic tourniquet cuff around the upper arm.
- As the hand will tend to be semisupinated internally rotate the shoulder to allow the hand to be placed in an appropriate pronated position for surgery.
- Bring in the image intensifier from the opposite side of the hand table.
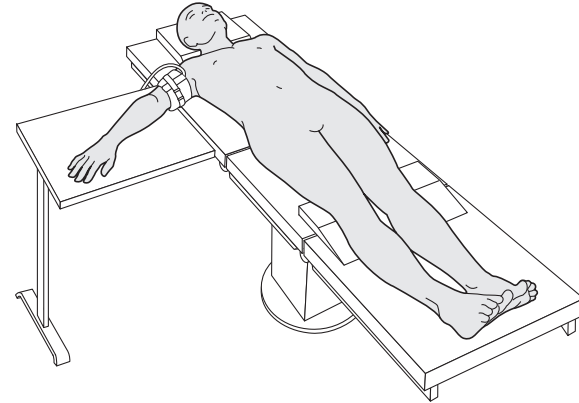
Fig 3.9.1-2

5 Skin disinfecting and draping

- Disinfect the entire hand, wrist, and arm with the appropriate antiseptic right up to the limits of the tourniquet cuff. This allows full exsanguination (Fig 3.9.1-3a).
- Preparation of the entire upper limb allows repositioning during surgery.
- If alcohol-based antiseptic is used, take care to ensure it does not run up under the tourniquet since skin damage can occur from prolonged contact with soaked material during surgery.

- A single-use occlusive hand drape with expandable arm opening is recommended (Fig 3.9.1-3b).
- Drape the image intensifier.
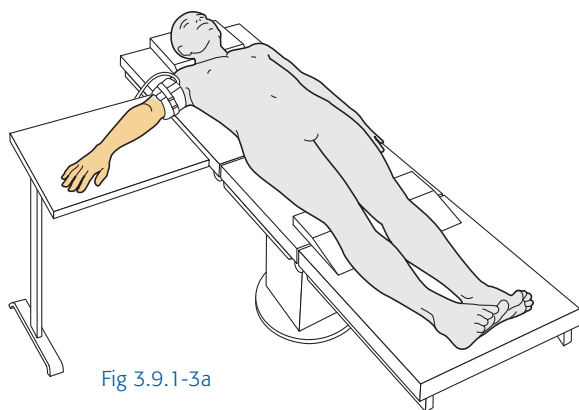
Fig 3.9.1-3a
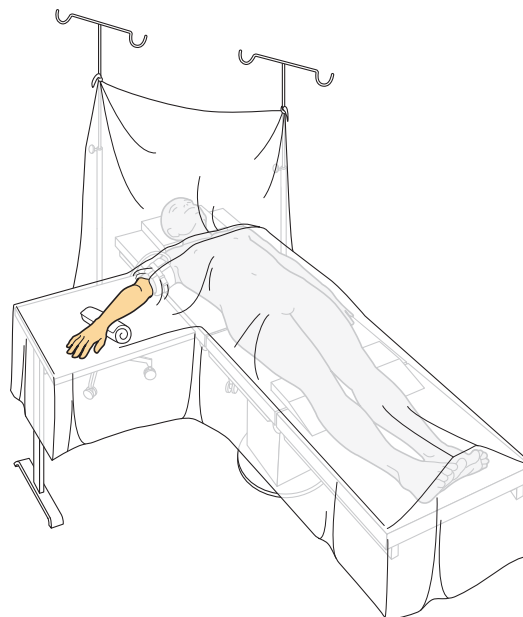
Fig 3.9.1-3b

6 Operating room set-up

- The surgeon sits beside the patient's head to gain a good view and access to the dorsum of the hand.
- The assistant sits opposite the surgeon.
- The ORP sits at the end of the hand table.
- Provide adjustable-height stools and protective lead gowns for all personnel involved.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.9.1-4).

Fig 3.3.1-4

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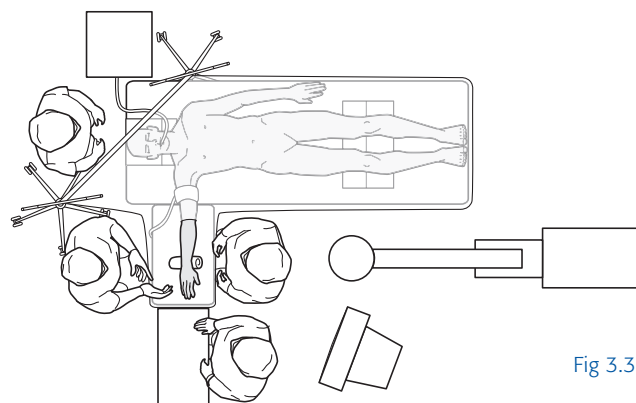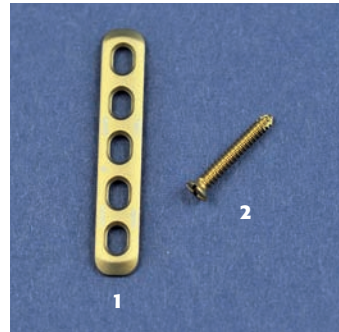
7   Instrumentation

Fig 3.9.1-5a   Implants
1.   LC-DCP 2.0 mm, 5 holes
2.   Cortex screw 2.0 mm, self-tapping
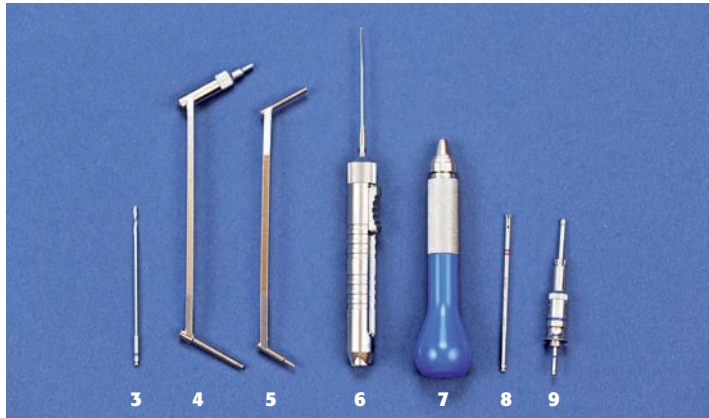
Fig 3.9.1-5b   Instruments for fracture fixation with LC-DCP 2.0
3.   Drill bit 1.5 mm
4.   Universal drill sleeve 2.0 mm
5.   Double drill sleeve 2.0/1.5 mm
6.   Depth gauge
7.   Handle with mini-quick coupling, medium
8.   Screwdriver shaft, self-holding
9.   Screwdriver shaft with holding sleeve
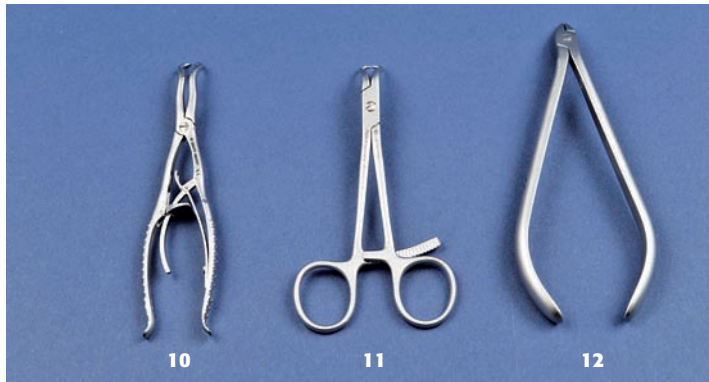
Fig 3.9.1-5c   Instruments for reduction and contouring
10.   Reduction forceps with points, narrow, soft lock
11.   Stagbeetle forceps, small
12.   Bending pliers, flat nosed, small

8   Procedure and technique—step-by-step

- Make a longitudinal incision over the dorsal aspect of the injured metacarpal or between adjacent injured metacarpals.
- Take care that the superficial approach identifies and protects small sensory nerve branches.
- Retract the extensor tendon. It may be necessary to divide the connections between adjacent extensor tendons (junctura tendinosum) to allow adequate retraction and appropriate visualization of the fracture. These structures must be repaired during closure.
- Open the periosteum longitudinally to reveal the fracture.
- Clean and reduce the fracture, removing hematoma, and interposed soft tissue.
- Confirm reduction using the image intensifier.
- Prebend a 5-hole LC-DCP 2.0 mm, if the palmar cortex is not fragmented.
- Apply the LC-DCP on the dorsal surface of the metacarpal.

- Insert two 2.0 mm cortex screws on one side of the fracture, ensuring that the plate sits on the dorsal surface of the bone along its length. Using the 1.5 mm drill bit and the double drill sleeve, drill a 1.5 mm hole in the neutral position, measure the depth, and insert a 2.0 mm self-tapping cortex screw (Fig 3.9.1-6a).
- Check the rotation of the digit.
- Make an eccentric 1.5 mm drill hole using the universal drill sleeve in the hole adjacent to the fracture (Fig 3.9.1-6b). Measure the depth and insert a 2.0 mm self-tapping cortex screw. Observe compression at the fracture site as the screw is tightened (Fig 3.9.1-6c).
- Insert a second cortex screw in the neutral position (Fig 3.9.1-6d).
- Perform and document a final x-ray check.
- Repair the periosteum with absorbable sutures.
- Close the wound.

Further information is available on AO Teaching video 22033: Transverse Fracture—Metacarpal II—2.0/5-hole LC-DCP.
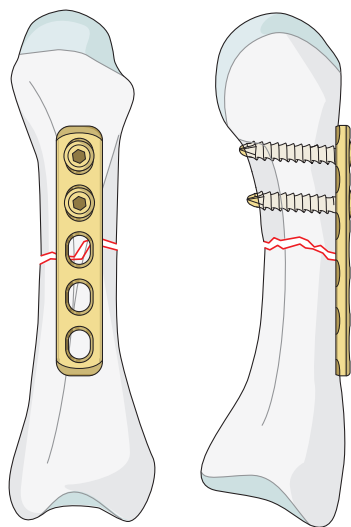
Fig 3.9.1-6a
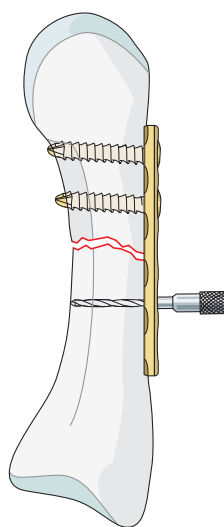
Fig 3.9.1-6b
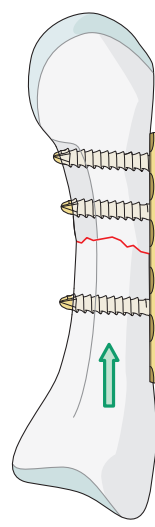
Fig 3.9.1-6c

Fig 3.9.1-6d

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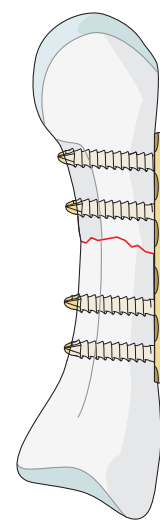
9   Specific perioperative care

- Make sure preoperative antibiotics are given.
- Protect the patient's arm from sharp instruments and drill bits.
- Cool the drill bit during drilling with continuous saline lavage. Drill bits can get hot, especially if they are not sharp. This can cause bone necrosis. Overheated drill bits are more prone to breakage.

- Measure each screw accurately immediately before insertion.
- Ensure the screw is securely mounted on the screwdriver.
- Maintain sterility of the image intensifier drape throughout the procedure.

10   Specific postoperative care

- Ensure the upper limb remains protected until regional anesthesia has worn off.
- Check for, and document, the presence and/or return of sensibility to all digits.
- Check the capillary refill of all digits regularly in the hours after surgery.

- Place the limb in a high-arm sling and encourage it to be worn constantly for the first 72 hours.
- Arrange physical therapy before discharge.
- Perform x-ray checks in the early days of rehabilitation and repeat until healing is demonstrated.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check air-powered drill and supply.

- Check pneumatic tourniquet and its air supply.
- Measure the length of each screw carefully before insertion.
- Remember cooling while drilling.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Ensure adequate x-rays are available.
- Check rotation of the digits repeatedly throughout the procedure.
- Regularly check the reduction on the image intensifier.
- Confirm the implant position and screw lengths using the image intensifier.
- If necessary divide the junctura tendinosum (connections between the extensor tendons on adjacent rays) to adequately mobilize the extensor tendons. Repair these on closure.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Doug Campbell

3.9.2   Scaphoid fracture: percutaneous fixation with 3.0 mm cannulated headless compression screw (HCS)

Surgical management

- Percutaneous fixation with 3.0 mm cannulated headless compression screw (HCS)

Alternative implant

- 3.0 mm or 2.4 mm cannulated screw

1   Introduction
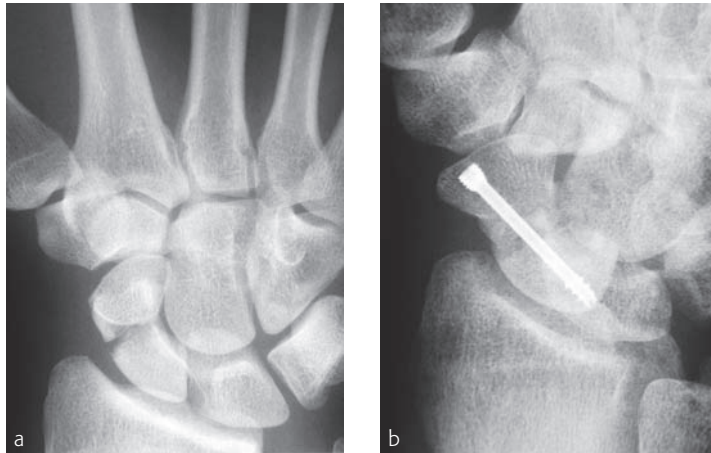
Fig 3.9.2-1a–b
a   Preoperative x-ray: displaced transverse scaphoid fracture.
b   Postoperative x-ray: stabilization with 3.0 mm cannulated headless compression screw (HCS).

- Fractures of the scaphoid and other carpal bones can be difficult to diagnose. The anatomical arrangement of this group of bones can make it difficult to see each bone individually on x-rays and multiple views, and further imaging such as CT or MRI is often required to confidently diagnose such injuries.
- Clinical symptoms and physical examination findings can vary from patient to patient. As a result, many patients with wrist pain after an injury are treated as if they have a fracture while awaiting either radiological proof or resolution of symptoms.
- The scaphoid has an unusual blood supply—entering the bone on the dorsal distal surface and flowing retrograde to the proximal pole. For this reason, fractures with displacement or those at the proximal end of the bone may well have a poor blood supply to the proximal part of the fracture. Such fractures are frequently managed by accurate reduction and stabilized by internal fixation to reduce the chances of nonunion.
- Some patients choose to have their undisplaced scaphoid fractures treated by percutaneous screw fixation. This allows them to spend less time in a cast, but it cannot be guaranteed that union will occur.
- Approximately 80–85% of undisplaced scaphoid fractures will heal when treated in a cast.
- The scaphoid bone lies obliquely across the wrist and its alignment changes with alteration of the position of the wrist. This can be used to the surgeon's advantage when performing percutaneous fixation.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned (percutaneous or open approach)
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Headless compression screw (HCS) 3.0 mm set
- Variety of screw lengths, both long and short thread
- General small orthopaedic instruments
- Small compatible air or battery drill with attachments

Equipment:
- Standard operating table
- Large hand table
- Image intensifier (a small one is suitable if available)
- X-ray protection devices for personnel and patient
- Tourniquet with exsanguinator

3 Anesthesia

- This procedure is performed with the patient under regional (eg, axillary) or general anesthesia.

4 Patient and x-ray positioning

- Position the patient supine and if under regional anesthesia make him/her comfortable with pillows under the head and under the knees.
- The hand is supine on a hand table (Fig 3.9.2-2).
- Apply a well padded pneumatic tourniquet cuff around the upper arm.
- Ensure the image intensifier has an uninterrupted path into and out of the surgical field.
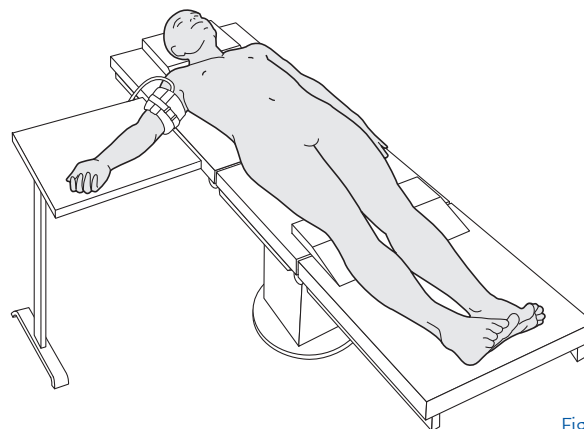
Fig 3.9.2-2

Author   Doug Campbell

5   Skin disinfecting and draping

- Disinfect the entire hand, wrist, and arm with the appropriate antiseptic right up to the limits of the tourniquet cuff. This allows full exsanguination (Fig 3.9.2-3a).
- Preparation of the entire upper limb allows repositioning during surgery.
- If an alcohol-based antiseptic is used, make sure it does not run up under the tourniquet since skin damage can occur from prolonged contact with soaked material during surgery.

- A single-use occlusive hand drape with expandable arm opening is recommended (Fig 3.9.2-3b).
- For percutaneous insertion, it is critical to control the orientation of the scaphoid by positioning the wrist in extreme extension and ulnar deviation. This is best achieved over a rolled towel (Fig 3.9.2-3c–d).
- Drape the image intensifier.
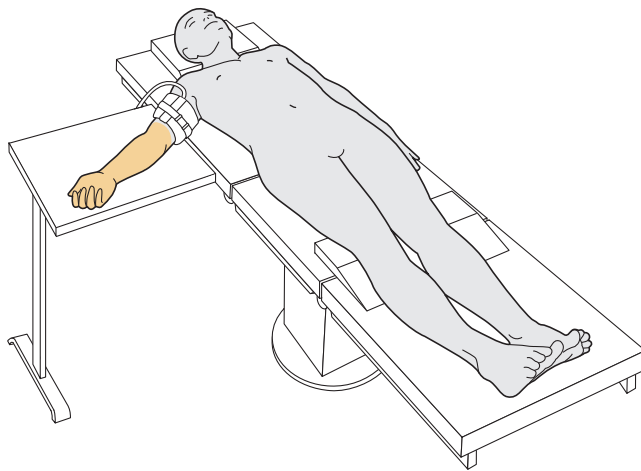
Fig 3.9.2-3a
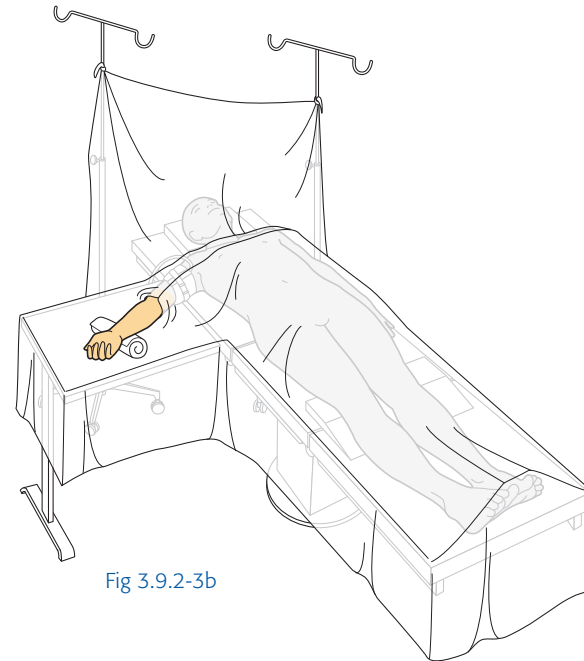
Fig 3.9.2-3b
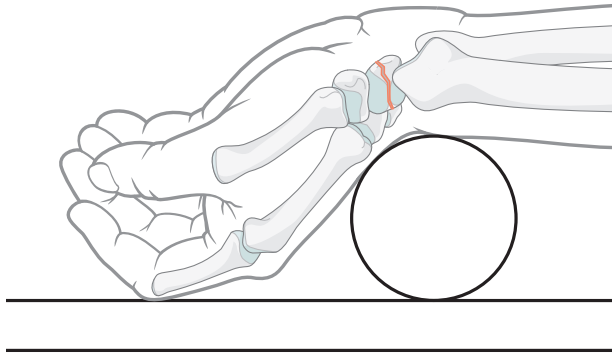
Fig 3.9.2-3c
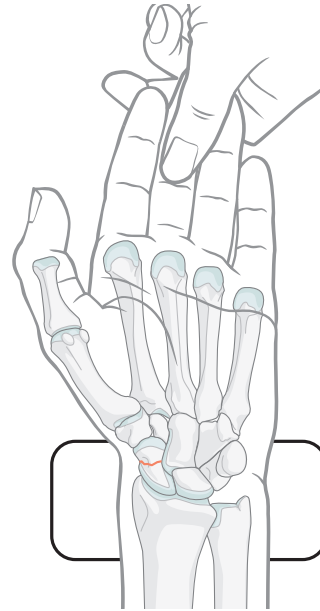
Fig 3.9.2-3d

6 Operating room set-up

- The surgeon sits at the end of the hand table to gain the best understanding of the anatomy and positioning of the scaphoid.
- The assistant sits in the patient's axilla to control the orientation of the wrist throughout the procedure.
- The ORP sits between the surgeon and the assistant.
- Provide adjustable-height stools and protective lead gowns for all personnel involved.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.9.2-4).

Fig 3.9.2-4

Author   Doug Campbell
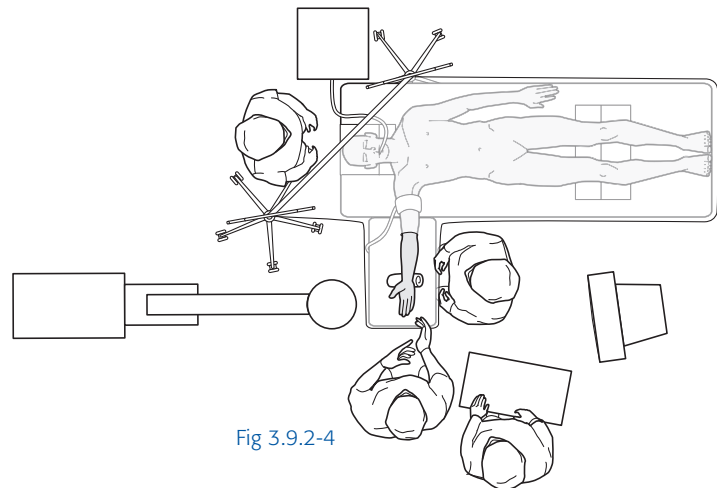
7   Instrumentation

Fig 3.9.2-5a   Implants
1.   Headless compression screws 3.0 mm, short and long thread
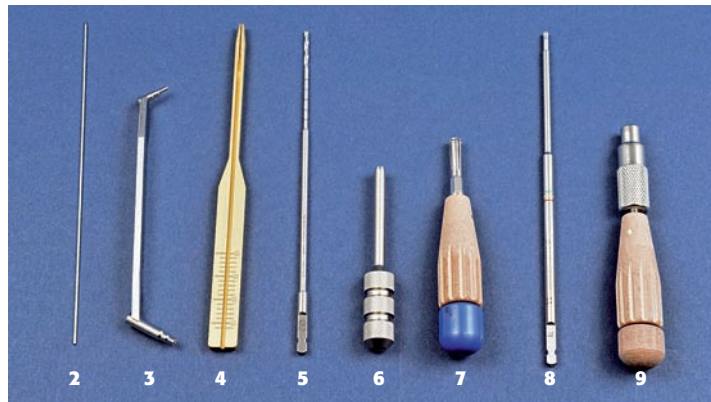
Fig 3.9.2-5b   Instruments for fracture fixation with headless compression screw
2.   Guide wire 1.1 mm, 150 mm long, with threaded tip
3.   Double drill sleeve 2.0/1.1 mm
4.   Direct measuring device for HCS
5.   Cannulated drill bit 2.0/1.15 mm
6.   Compression sleeve for HCS 3.0 mm
7.   Handle for compression sleeve
8.   Screwdriver shaft, cannulated
9.   Handle with quick coupling

Fig 3.9.2-5c   Instruments for implant removal
10.   Compression sleeve for HCS 3.0 mm
11.   Screwdriver shaft
12.   Handle with quick coupling

8 Procedure and technique—step-by-step

- Using the image intensifier, position the wrist in full extension over a rolled towel so as to reduce the fracture and obtain the best angle for the guide wire insertion. Once the wrist has been placed in the optimum position, it must not be moved again until the guide wire has been inserted.
- Mark the skin with a surgical marking pen to demonstrate the scaphotrapezial joint, the radioscaphoid joint, and the long axis of the scaphoid only after achieving fracture reduction.
- Incision: make a 1 cm transverse incision over the scaphotrapezial joint. Use blunt dissection through the thenar muscles to enter the scaphotrapezial joint.
- The most important step in this procedure is to identify and choose the correct entry point. The entry point should be centrally in the distal pole of the scaphoid, so the implant will insert along the long axis of the bone, not obliquely across it. It is often necessary to remove the overhanging edge of the trapezial ridge with a rongeur or small osteotome to reveal the correct entry point (Fig 3.9.2-6a).
- Insert a 1.1 mm threaded guide wire with the corresponding double drill sleeve along the long axis of the scaphoid under the guidance of the image intensifier.
- Check the position of the guide wire on several views to ensure that the tip of the wire remains within the scaphoid (Fig 3.9.2-6b).
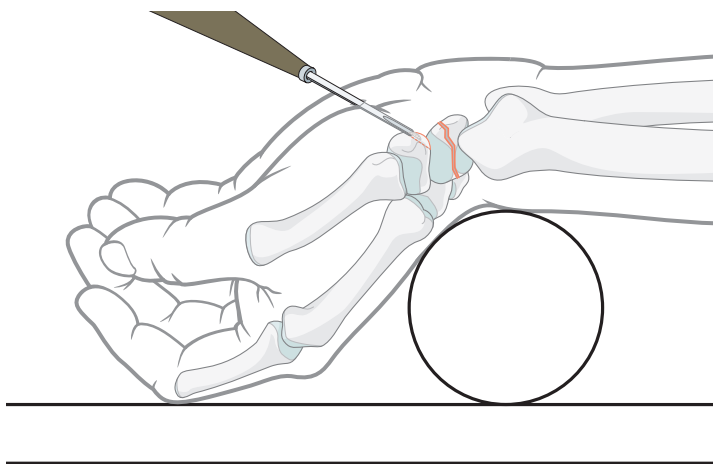
Fig 3.9.2-6a

Fig 3.9.2-6b

Author Doug Campbell
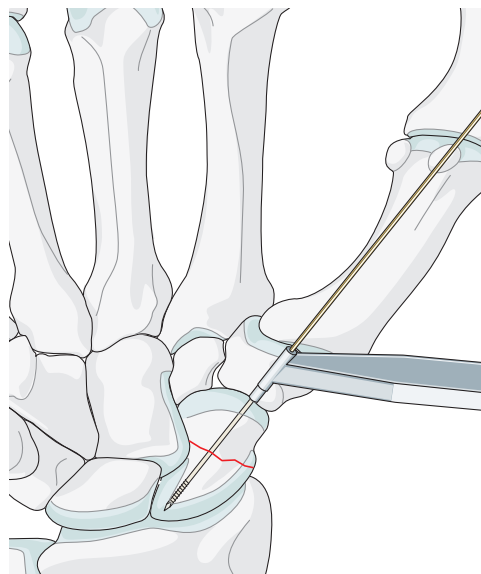
- Slide the narrow end of the measuring device over the guide wire, and measure the depth of screw required (Fig 3.9.2-6c). Subtract 2 mm for countersinking and a further 1 mm (or more if indicated) to allow for compression at the fracture site.
- Determine the definitive screw length and thread length.
- Over drill the guide wire using the 2 mm cannulated drill bit and drill sleeve. Do not over drill the threaded portion of the guide wire (Fig 3.9.2-6d). Make sure that the guide wire is not inadvertently removed during this step.
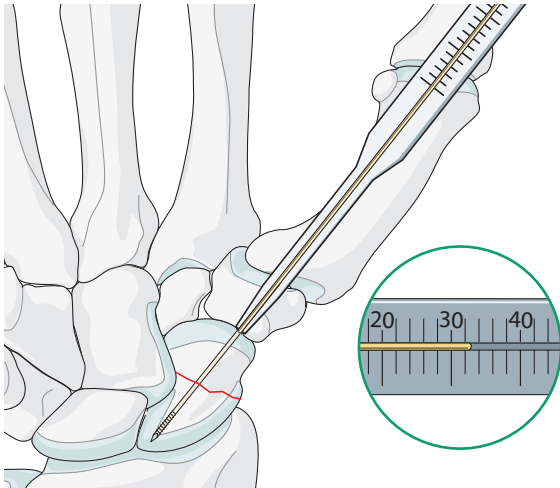
Fig 3.9.2-6c
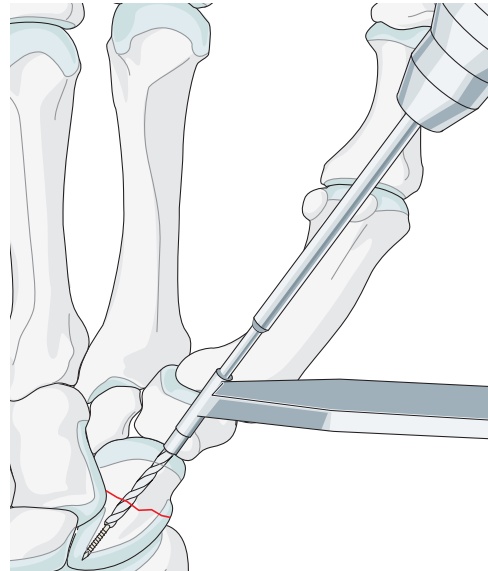
Fig 3.9.2-6d

- Screw the compression sleeve onto the head of the selected screw, and insert the handle for the compression sleeve (which clicks into place) into the sleeve/screw assembly. Using the sleeve/handle assembly introduce the screw over the guide wire (Fig 3.9.2-6e). Observe the screw's progress using the image intensifier.
- When the compression sleeve touches the scaphoid, further insertion will result in compression at the fracture site. This is because the sleeve hides the proximal threaded portion so the screw behaves as a lag screw (Fig 3.9.2-6f).

- When applying compression there is a danger of causing a rotational displacement of the fracture fragments due to the high torque resistance of dense cancellous bone. Inserting a second parallel antirotation guide wire can prevent this.
- When the desired amount of compression is achieved, remove the handle of the compression sleeve, and insert the cannulated screwdriver shaft with colored markings attached to the handle. When the screwdriver is correctly seated in the screw head recess, the green line will be visible at the collar of the compression sleeve (Fig 3.9.2-6g).
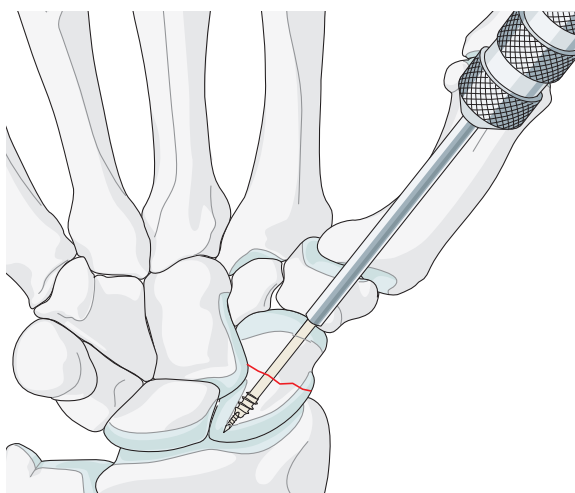
Fig 3.9.2-6e
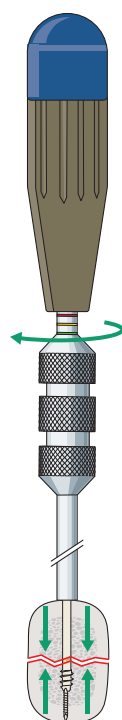
Fig 3.9.2-6f

Fig 3.9.2-6g

Author Doug Campbell
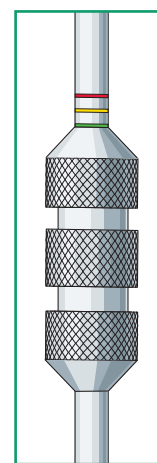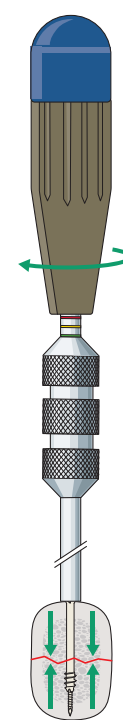
- Hold the compression sleeve firmly between the fingers of one hand to prevent further rotation, and advance the screw by turning the screwdriver. Compression will be maintained by the compression sleeve as the screw is advanced into the bone. When the yellow line is level with the compression sleeve collar, the screw head is level with the bone surface. Further insertion until only the red line is visible represents 2 mm of countersinking (Fig 3.9.2-6h).
- Remove the guide wire (Fig 3.9.2-6i).
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 22061: Scaphoid Fracture—Percutaneous Fixation with the 3.0 mm Headless Compression Screw (HCS).
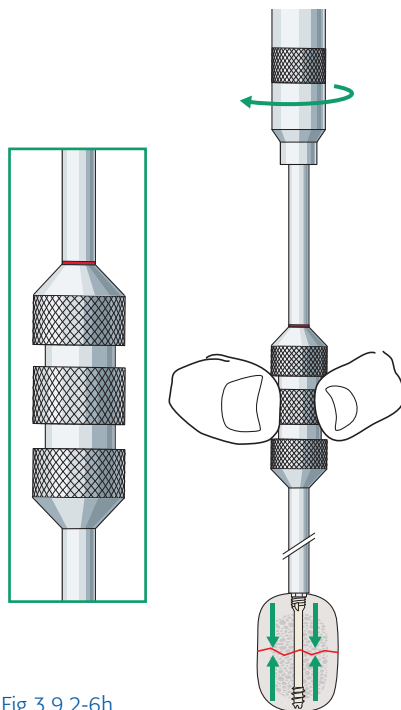
Fig 3.9.2-6h
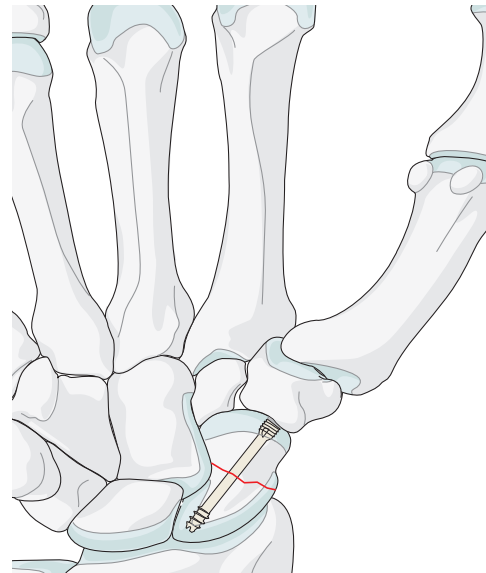
Fig 3.9.2-6i

9   Specific perioperative care

- Ensure preoperative antibiotic prophylaxis is given.
- Protect the patient's upper limb from sharp instruments and drill bits during surgery.
- Assign an assistant to be responsible for maintaining the selected position of the wrist throughout the procedure.

10   Specific postoperative care

- Ensure the upper limb remains protected until regional anesthesia has worn off.
- Check for, and document, the presence and/or return of sensibility to all digits.
- Regularly check the capillary refill of all digits in the hours after surgery.
- Place the limb in a high-arm sling and encourage the patient to wear it constantly for the first 72 hours.
- Perform x-ray checks to confirm implant placement, and repeat regularly until evidence of radiological union.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Ensure that the full range of implants and instruments are available.
- Check the air-powered drill and supply.
- Check the pneumatic tourniquet and its air supply.
- Have several additional guide wires available.
- Provide a new guide wire for each attempt at insertion. They become blunt after use and are not reliable for repeated use.
- Discard guide wires after usage.
- Ensure the instruments are assembled correctly and given to the surgeon in the correct order.
- Carefully clean the cannulated drill bit. The guide wire will frequently stick within the drill bit and requires careful removal.
- Remember cooling while drilling.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Take time to position the wrist correctly and make accurate surface markings.
- Do not reposition the wrist after initial orientation.
- Concentrate on identifying and making the correct entry point.
- Repeat the insertion of the guide wire until its position is ideal.
- Do not over drill the threaded portion of the guide wire.
- Calculate the correct screw length carefully.
- Monitor the screw's progress with the image intensifier during insertion.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Doug Campbell

3.9.3   Unicondylar phalangeal fracture: stabilization with 1.5 mm cortex screw

Surgical management

- Stabilization with 1.5 mm cortex screw applied as lag screw

Alternative implant

- 1.3 or 2.0 mm cortex screw (lag screw technique) depending on fragment size

1   Introduction
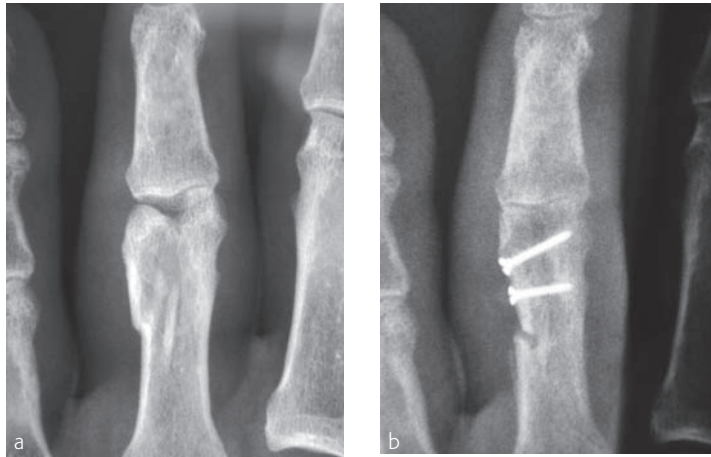
Fig 3.9.3-1a–b
a   Preoperative x-ray: displaced partial articular fracture of distal end of proximal phalanges.
b   Postoperative x-ray: stabilization with 1.5 mm cortex screw.

- Displaced articular phalangeal fractures are likely to result in painful, stiff joint function if not anatomically reduced. Early arthrosis is not uncommon.
- Fixation must be sufficiently stable to allow early movement.
- The anatomy of the finger joints demands a careful surgical approach.
- Lag screw fixation provides anatomical reduction, interfragmentary compression, and provides absolute stability to allow essential early rehabilitation.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Compact hand set 1.5 mm and 1.3 mm
- General small orthopaedic instruments
- Micro drive or similar small compatible air or battery drill with attachments

Equipment:
- Standard operating table
- Large hand table
- Image intensifier (a small one is suitable if available)
- X-ray protection devices for personnel and patient
- Tourniquet with exsanguinator

3 Anesthesia

- Regional (eg, axillary) or general anesthesia is recommended. It is possible to perform this procedure with the patient under local anesthetic digital block, but it is unlikely to be comfortable and it is not easy to maintain a bloodless field.

Author   Doug Campbell

4   Patient and x-ray positioning

- Position the patient supine and if under regional anesthesia make him/her comfortable with pillows under the head and under the knees (Fig 3.9.3-2).
- The shoulder is only anesthetized by a high block (interscalene or supraclavicular). Patients with coexistent shoulder pathology must be positioned carefully to avoid discomfort.
- Apply a well padded pneumatic tourniquet cuff around the upper arm.
- The hand will tend to be semisupinated. Internal rotation of the shoulder will allow the hand to be placed in an appropriate pronated position for surgery.
- Bring in the image intensifier from the opposite side of the hand table.
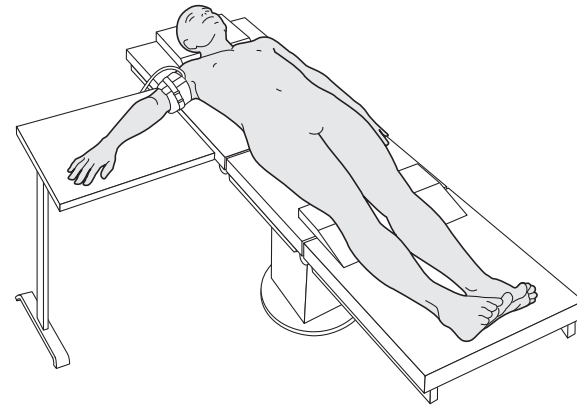
Fig 3.9.3-2

5 Skin disinfecting and draping

- Disinfect the entire hand, wrist, and arm with the appropriate antiseptic right up to the limits of the tourniquet cuff. This allows full exsanguination (Fig 3.9.3-3a).
- Preparation of the entire upper limb allows repositioning during surgery.
- If an alcohol-based antiseptic is used, make sure it does not run up under the tourniquet since skin damage can occur from prolonged contact with soaked material during surgery.

- A single-use occlusive hand drape with expandable arm opening is recommended (Fig 3.9.3-3b).
- Drape the image intensifier.
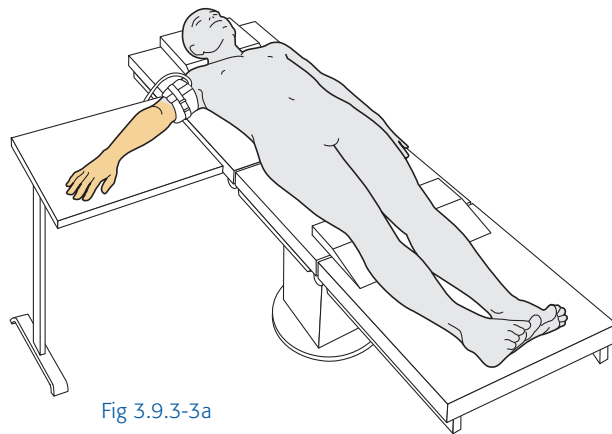
Fig 3.9.3-3a

Fig 3.9.3-3b

Author   Doug Campbell

6   Operating room set-up

- The surgeon sits at the head of the table to gain access to the dorsum of the finger.
- The assistant sits at the end of the hand table.
- The ORP sits between the surgeon and the assistant.
- Provide adjustable-height stools and protective lead gowns for all personnel involved.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.9.3-4).
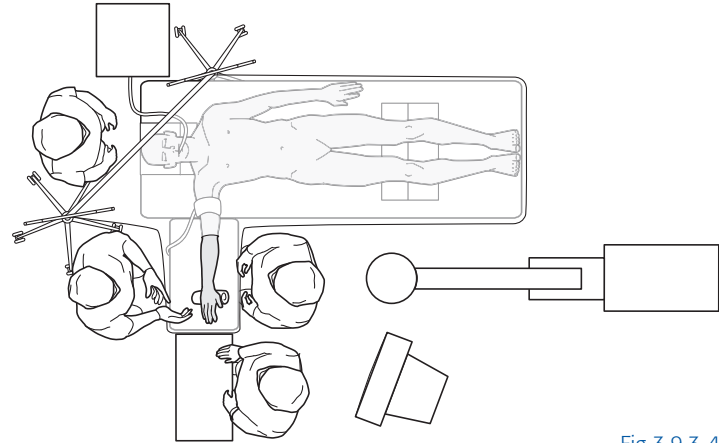
Fig 3.9.3-4

7 Instrumentation

Fig 3.9.3-5a   Implants
1.   Self-tapping screws 1.5 mm
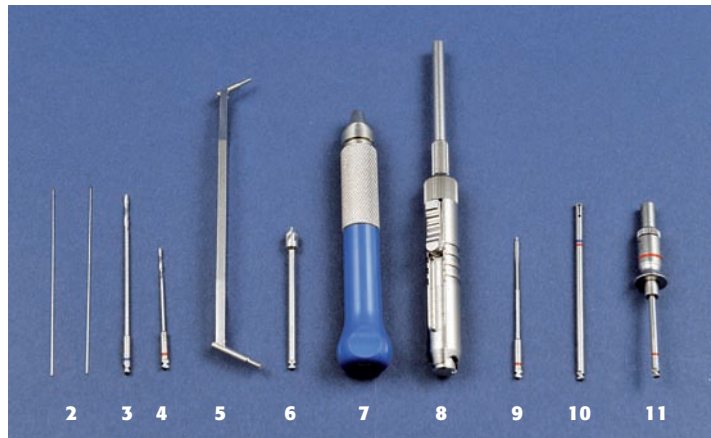
Fig 3.9.3-5b   Instruments for fracture fixation with 1.5 mm cortex screw
2.   K-wires 0.6 mm
3.   Drill bit 1.5 mm
4.   Drill bit 1.1 mm
5.   Double drill sleeve 1.5/1.1 mm
6.   Countersink 1.5–2.4 mm
7.   Handle, with mini-quick coupling
8.   Depth gauge
9.   Tap 1.5 mm
10. Screwdriver shaft, self-holding
11. Screwdriver shaft with holding sleeve

Author   Doug Campbell

8   Procedure and technique—step-by-step

- Make a 1 cm mid-axial incision to avoid injury to the dorsal tendons and other gliding structures.
- Expose the fracture initially using blunt dissection, being careful to avoid the neurovascular structures.
- Perform careful articular reduction using a pointed reduction forceps and a 0.6 mm K-wire if required. If a K-wire is used, do not put it where a lag screw will be placed (Fig 3.9.3-6a).
- Avoid injury to the collateral ligament by placing the screw proximal to the origin of the ligament.
- Use the lag screw technique. First, drill the core hole through both fragments with the 1.1 mm drill bit and drill sleeve; measure the depth, then over drill the near fragment with a 1.5 mm drill bit to create the gliding hole (Fig 3.9.3-6b–d) and insert the appropriate screw.

- If the fracture geometry allows, place a second lag screw. This will help to control rotation of the fragment. This screw can be inserted at the site of a K-wire which had been used to hold the fracture reduction during insertion of the first screw. The hole made by the K-wire is over drilled using the 1.5 mm drill bit to create the gliding hole in the near cortex. The far cortex is drilled using the 1.1 mm drill bit (Fig 3.9.3-6e–f).
- Check the reduction using the image intensifier.
- Check the rotation of the fingers by clinically assessing their relative positions in flexion.
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 22034: Unicondylar Fracture—Head of the Proximal Phalanx of the Thumb—2.0 mm Lag Screw.
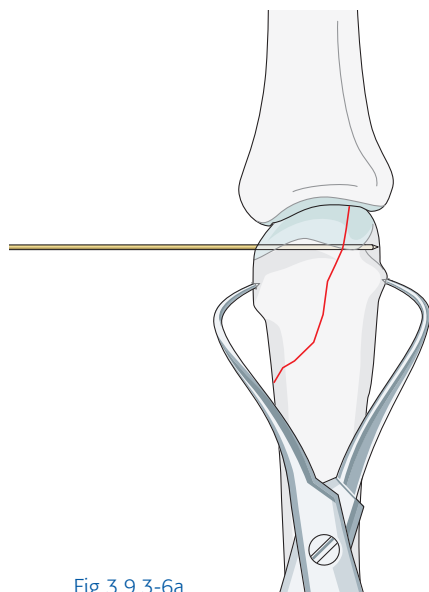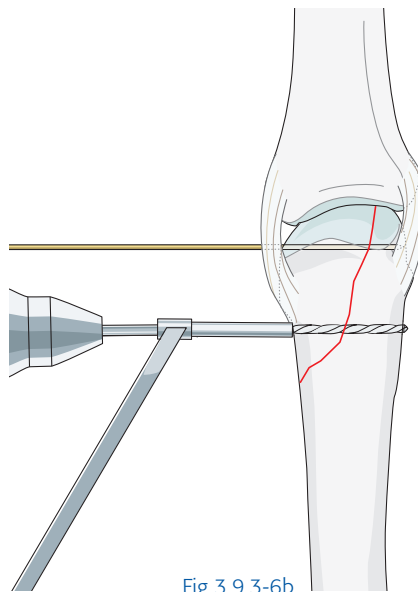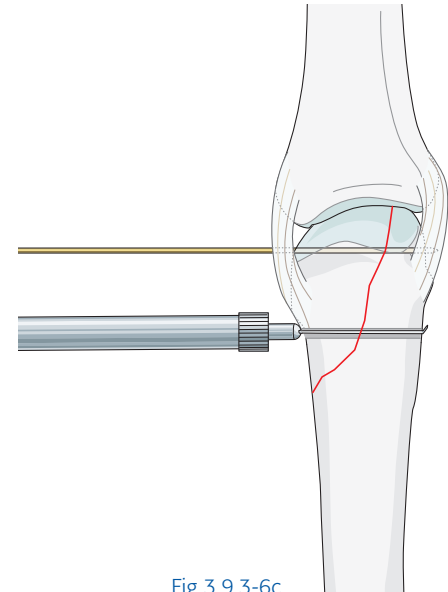
Fig 3.9.3-6a   Fig 3.9.3-6b   Fig 3.9.3-6c
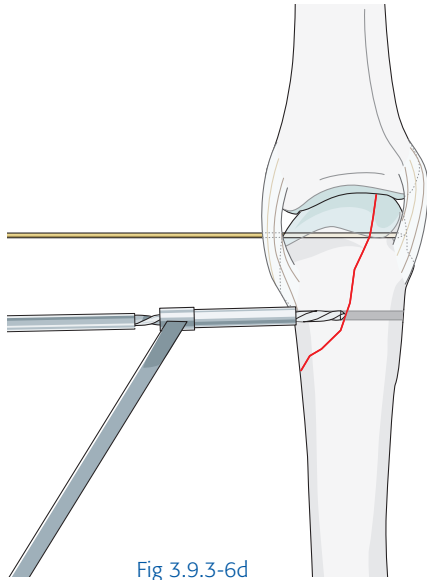
Fig 3.9.3-6d
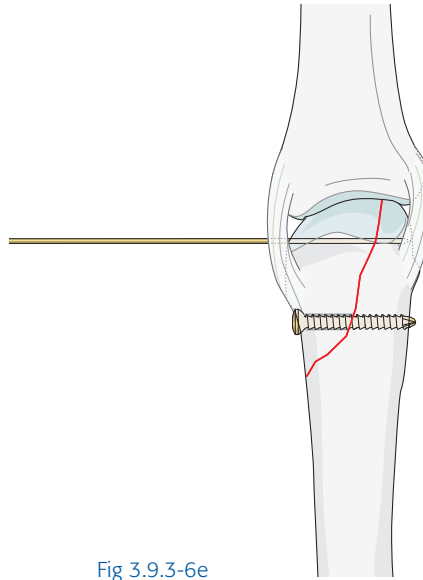
Fig 3.9.3-6e
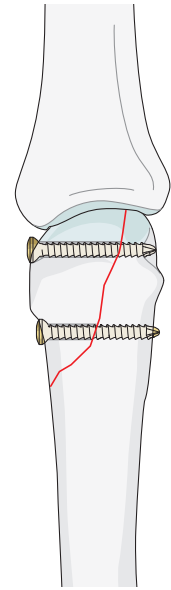
Fig 3.9.3-6f

9 Specific perioperative care

- Ensure preoperative antibiotics are given.
- Protect the patient's arm from sharp instruments and drill bits.
- Ensure correct drill bits are used in the correct order.
- Carefully cool the drill bit during drilling by continuous saline lavage. Drill bits can get hot, especially if they are not sharp. This can cause bone necrosis. Overheated drill bits are more prone to breakage.

- Accurately measure each screw immediately before insertion.
- Ensure the screw is securely mounted on the screwdriver.
- Maintain sterility of the image intensifier drape throughout the procedure.

Author   Doug Campbell

10   Specific postoperative care

- Ensure the upper limb remains protected until regional anesthesia has worn off.
- Check for, and document, the presence and/or return of sensibility to all digits.
- Regularly check the capillary refill of all digits in the hours after surgery.
- Place the limb in a high-arm sling and encourage it to be worn constantly for the first 72 hours.
- Arrange early physical therapy, edema control, and range of motion exercises.
- Perform x-ray checks in the early days of rehabilitation and repeat until healing is demonstrated.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of screws and instruments are available before surgery.
- Have spare drill bits of appropriate size available.
- Check the air-powered drill and supply.
- Check the pneumatic tourniquet and its air supply.
- Carefully measure screw length for each screw immediately before insertion.
- Remember cooling while drilling.
- Document and reorder all screws used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Construct a preoperative plan for fixation and inform the ORP.
- Ensure adequate x-rays are available.
- Check rotation of the digits repeatedly throughout the procedure.
- Regularly check the reduction on the image intensifier.
- Check the implant position and screw lengths using the image intensifier.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.10 Pelvic ring fractures

Author   AD Patel

3.10   Pelvic ring fractures

Implants and surgical technique

- Large external fixator
- LC-DCP 4.5 narrow

Cases

- Application of external fixator to unstable pelvic ring fracture (61-C1)
- Plate fixation of disrupted pubic symphysis (61-B1)

Introduction

- According to the Müller AO/OTA Classification, the pelvis is bone 6 and the pelvic ring is designated 61:
  - 61-A: isolated fractures with no pelvic ring instability
  - 61-B: partial pelvic ring disruption with posterior sacroiliac structures intact
  - 61-C: complete pelvic ring disruption
- Isolated fractures of the pelvis which do not disrupt the pelvic ring are usually low-energy injuries, often seen in the elderly with osteoporotic bone. Most can be treated nonoperatively.
- Injuries causing disruption of the pelvic ring are the result of high-energy trauma and are frequently life-threatening.
- The disruption causes damage to blood vessels running through the pelvis. The opening up of the ring increases the volume and allows space for massive bleeding while continuing movement of the unstable pelvis disrupts hematoma formation. This in turn causes further bleeding.
- Immediate management should include fluid resuscitation and the application of a pelvic binder to try and normalize pelvic volume while minimizing pelvic movement to prevent disruption of the hematoma within the pelvic cavity.
- These measures are often sufficient to control pelvic blood loss and stabilize patients. Continuing hemodynamic instability due to pelvic bleeding is a major emergency. Patients may require the application of an external fixator and pelvic packing. In specialist facilities angiography to identify any arterial source of bleeding can be carried out. If a source of bleeding is identified, using this technique the bleeding can often be controlled by injecting thrombotic substance into the affected vessel causing a clot to form and bleeding to cease (radiographic embolization).
- Subsequent definitive stabilization of the disrupted pelvic ring in the hemodynamically stable patient should occur within 14 days of injury and is likely to require transfer to a specialist center.

Müller AO/OTA Classification—pelvic fracture

61-A1
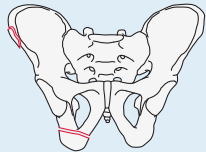
61-A2
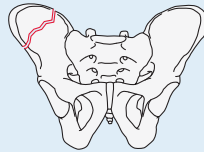
61-A3
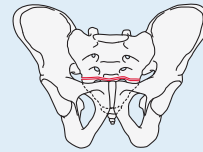
61-A   pelvis, ring, stable
61-A1   fracture of innominate bone, avulsion
61-A2   fracture of innominate bone, direct blow
61-A3   transverse fracture of sacrum and coccyx

61-B1
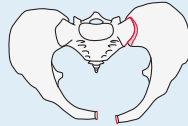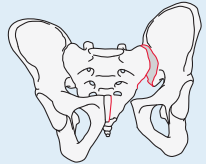
61-C1
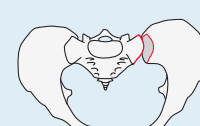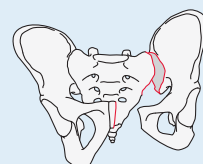
61-B2
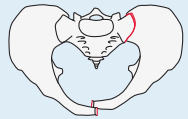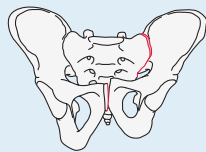
61-C2
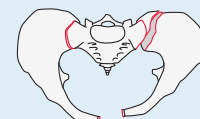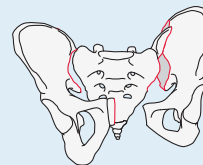
61-B3
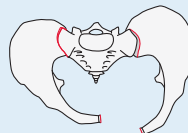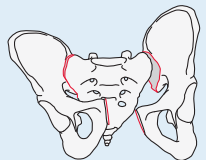
61-C3
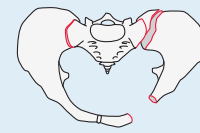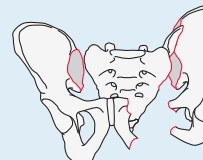
61-B   pelvis, ring, partially stable
61-B1   unilateral, partial disruption of posterior arch, external rotation
   ("open-book" injury)
61-B2   unilateral, partial disruption of posterior arch, internal rotation
   (lateral compression injury)
61-B3   bilateral, partial lesion of posterior arch

61-C   Pelvis, ring, complete disruption of posterior arch unstable
61-C1   unilateral, complete disruption of posterior arch
61-C2   bilateral, ipsilateral complete, contralateral incomplete
61-C3   bilateral, complete disruption

Author   AD Patel

3.10.1 Pelvic ring fracture with complete pelvic ring disruption (61-C1): stabilization with large external fixator

Surgical management

- Stabilization with large external fixator

Alternative implant

- Pelvic C-clamp

1 Introduction

- Use of external fixation of the unstable pelvic ring fracture is indicated for those patients who remain hemodynamically unstable despite fluid resuscitation and application of a pelvic binder.
- In these circumstances surgery is almost always performed as an emergency in an attempt to save the patient's life, and precedes attempts to stop the bleeding by packing the pelvis and/or a laparotomy for intraabdominal trauma.
- External fixation is used as a temporizing measure in patients who require stabilization of their pelvic fracture for transfer to a specialist unit for definitive treatment.
- External fixation may also be used as a temporizing measure for patients in whom the definitive treatment of their pelvic injury needs to be delayed because of their general condition.

- The timing of definitive surgery depends on many factors, especially the general condition of the patient. A damage-control strategy is frequently adopted (see chapter 2.9).
- External fixation is also used as definitive treatment in patients with partial pelvic ring disruption who have the posterior sacroiliac structures intact.
- Unstable patients are often in extremis and may arrive in the operating room with little or no notice.
- External fixator pins may be fixed to the iliac crest or to the supraacetabular area of the pelvis.
- The iliac crest site is easier to identify, technically less demanding, and faster to apply; although the fixation is less secure and provides little control over any posterior pelvic ring instability.

Fig 3.10.1-1a–b
a   Preoperative x-ray: C-type pelvic ring fracture showing vertical and rotational instability.
b   Postoperative x-ray: emergency stabilization using large external fixator.

- This technique should always be used for emergency fixation by inexperienced surgeons and does not require the use of an image intensifier.
- The supraacetabular technique is technically demanding. The use of an image intensifier is mandatory. Orientation is difficult due to the displacement of the fracture. Inadvertent penetration of the hip may occur and the neurovascular bundle which lies directly anterior to the hip joint is also potentially at risk.

- The supraacetabular technique however has significant advantages over the iliac crest technique. The quality of the bone and the quality of fixation is better in the supraacetabular area of the pelvis. Pins inserted in this area give better compression of the pelvis and more control over the posterior structures.
- Because of the potential dangers of the supraacetabular technique, it should only be used by experienced surgeons; ideally when speed is not of critical importance.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site of fracture
- Type of operation planned
- Condition of the soft tissues
- Implants to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Large external fixator set
- Laparatomy emergency set
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Use a radiolucent pelvic table, if available, to permit AP, inlet, and outlet images. If not available, use a standard operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general anesthesia.
- The patient may have been anesthetized as part of the resuscitation process before reaching the operating room.

Author   AD Patel

4   Patient and x-ray positioning

- The patient is placed in the supine position with a roll under the knees and the legs kept tied together (Fig 3.10.1-2). The legs should be internally rotated. This closes an "open book" pelvic ring fracture (61-B1).
- Care should be taken when transferring the patient to minimize movement of the pelvic ring fracture.
- Make sure that any other injuries are not made worse by positioning the patient.
- Protect pressure areas.
- Ideally the table should allow for image intensifier access to the pelvis, although this is not always possible.
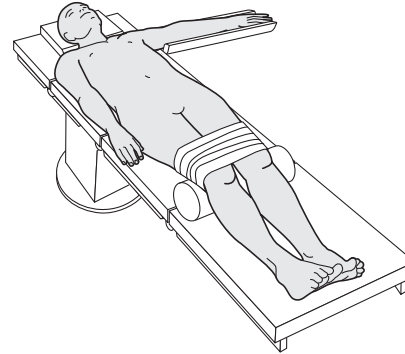
Fig 3.10.1-2

5   Skin disinfecting and draping

- Disinfect the exposed area from the knees to mid-thorax and as laterally as possible with the appropriate antiseptic (Fig 3.10.1-3a).
- Draping should expose both iliac crests and allow for the possibility of a subsequent laparotomy or pelvic-packing procedure (Fig 3.10.1-3b).
- Drape the image intensifier.
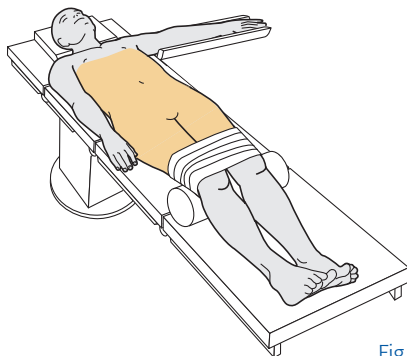
Fig 3.10.1-3a
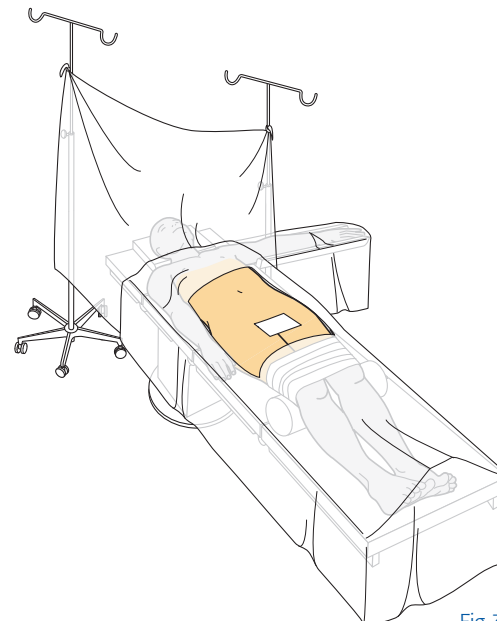
Fig 3.10.1-3b

6 Operating room set-up

- The surgeon stands on one side of the patient.
- The assistant stands opposite the surgeon.
- The ORP sets up adjacent to the surgeon.
- The image intensifier comes in from the side opposite the surgeon.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.10.1-4).

Fig 3.10.1-4

Author   AD Patel
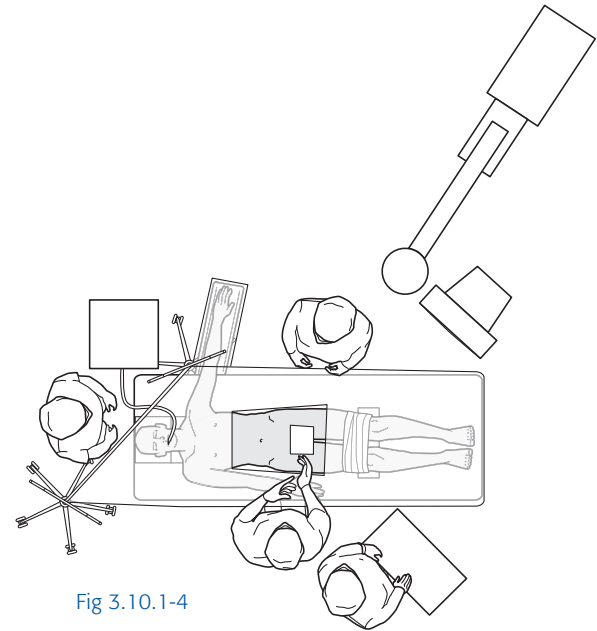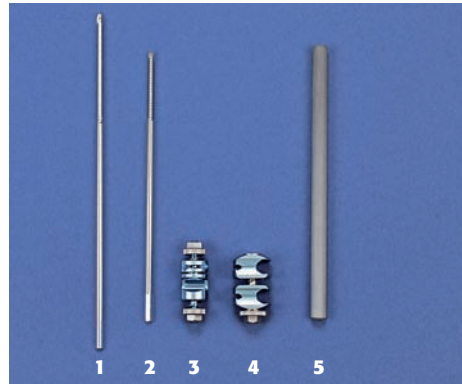
7   Instrumentation

Fig 3.10.1-5a   Implants
1.   Seldrill Schanz screw 5.0 mm
2.   Schanz screw 5.0 mm
3.   Self-holding clamp
4.   Self-holding combination clamp
5.   Carbon fiber rod 11 mm
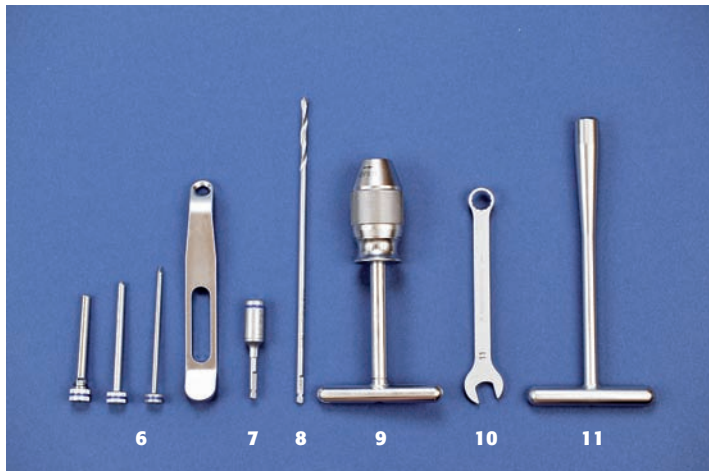
Fig 3.10.1-5b   Instruments for fracture fixation with external fixator
6.   Triple drill sleeve assembly (drill sleeve 6.0/5.0 mm, drill sleeve 5.0/3.5 mm, trocar 3.5 mm, and handle)
7.   Adapter for Seldrill Schanz screws 5.0 mm
8.   Drill bit 3.5 mm
9.   Universal chuck with T-handle
10.   Combination wrench 11 mm
11.   Socket wrench 11 mm

8   Procedure and technique—step-by-step

Iliac crest technique

- Make a 2 cm incision, 1 cm posterior to the anterosuperior iliac spine, centered on, but at a right angle to the iliac crest.
- Be sure to identify the position of the iliac wing accurately. It may have been displaced because of the pelvic ring injury.
- Identify the iliac bone by blunt dissection.
- Insert a 2 mm K-wire each side of the iliac wing, running the tip of the wire down the bone surface, to determine its exact orientation (Fig 3.10.1-6a).
- Place the triple sleeve assembly on the iliac crest aiming to bisect the angle between the two K-wires (Fig 3.10.1-6b).
- If Seldrill Schanz screws are used, remove the trocar and inner sleeve of the triple guide.

- Mount a long 5 mm Seldrill Schanz screw into the quick coupling of a drill and insert the screw till the outer cortex has been penetrated and it begins to advance. Aim toward the hip joint.
- Once the threads have engaged, remove the drill, and insert the screw by hand using the universal chuck with T-handle.
- If a conventional Schanz screw is used, remove the trocar, drill the outer cortex of the iliac wing with a 3.5 mm drill bit, and insert the screw by hand with the universal chuck with T-handle.
- If the image intensifier is available, check the position of the screw within the bone.
- Insert the Schanz screw until the threads are no longer visible.
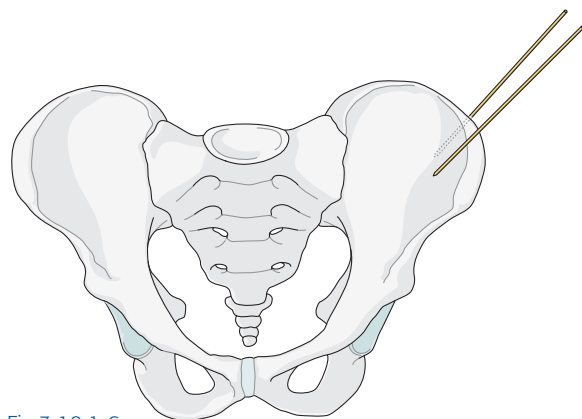
Fig 3.10.1-6a

Fig 3.10.1-6b

Author   AD Patel
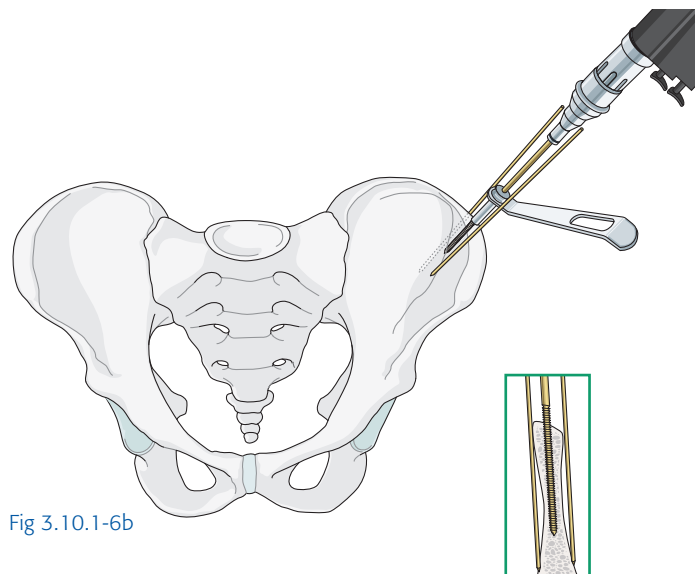
- Insert a second Schanz screw using the same technique as far posteriorly on the iliac crest as is easily accessible without moving the patient (Fig 3.10.1-6c). Because there is a lateral overhang on the posterior part of the iliac crest, insert this screw slightly medial to the mid part of the crest.
- The iliac crest is triangular in cross-section and narrows down considerably by 2–3 cms from the subcutaneous surface of the bone. Inserting Schanz screws that run between the two bone cortices is therefore more difficult than it would appear to be at first sight. Schanz screws frequently protrude through one cortex and the quality of hold that each screw has must be carefully assessed. Two well fixed screws are usually sufficient to achieve stability, but if in any doubt insert a third screw.

- The tips of the screws are aimed to converge just above the acetabulum.
- Place a pin-to-bar clamp (self-holding clamp) on each Schanz screw. If available magnetic resonance imaging safe clamps and carbon fiber rods should be used as they facilitate subsequent imaging.
- Connect the two clamps with a short rod which extends anterior to the anterior Schanz screw by about 5 cm (Fig 3.10.1-6d).
- Attach a combination clamp to the anterior part rod connecting the Schanz screws and use it to attach a longer rod which extends toward the midline of the pelvis, making up half of the frame construct. Tighten the nuts by hand.
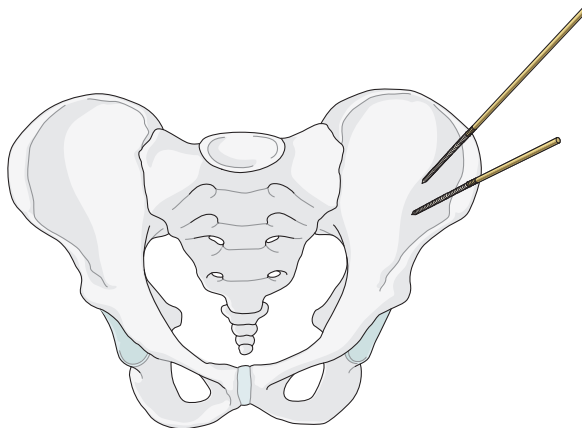
Fig 3.10.1-6c
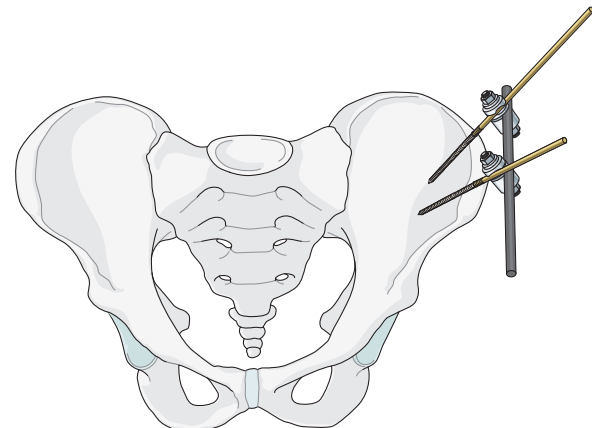
Fig 3.10.1-6d

- Perform an identical procedure on the contralateral iliac crest. If possible, this may be done by a second surgeon to shorten the procedure time.
- The long rods from each side can then be connected by a combination clamp anteriorly in the midline distal to the level of the pubic symphysis, allowing access for a laparotomy or pelvic packing as required (Fig 3.10.1-6e).
- Adjust the position of the pelvis by pushing on the greater trochanter to compress the pelvis under the image intensifier control to restore the anatomy to as normal a position as possible.
- Tighten all nuts with an 11 mm wrench.
- Dress the pin sites.

Supraacetabular technique

- Mark the anterosuperior iliac spines (ASIS) on both sides with a skin marker.
- Using a ruler mark the entry point of the Schanz screws 5 cm distal and 3 cm medial to ASIS.
- Place the image intensifier for an outlet view of 30º and rotate it outward (approximately 20º) until the iliac spine is seen in profile and the anteroinferior iliac spine is viewed as a large tear-shaped structure.
- Incise the skin and deepen the approach using blunt dissection until the anteroinferior iliac spine is identified.
- Insert the triple sleeve assembly to lie just below the anteroinferior iliac spine and confirm the position using the image intensifier.

Fig 3.10.1-6e

Author   AD Patel
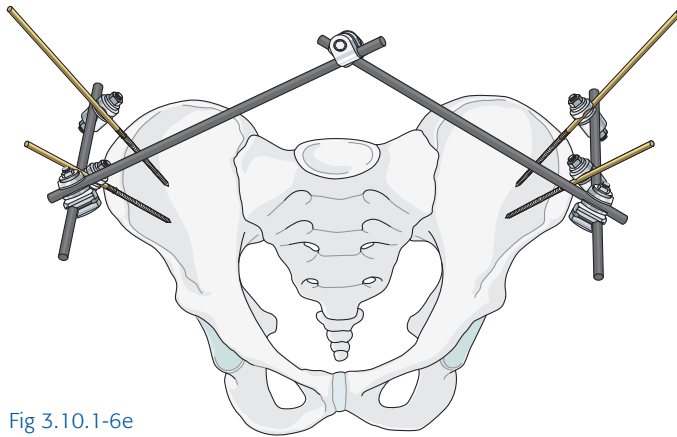
- If Seldrill Schanz screws are used, mount a 5 mm screw on a drill using the quick coupling adapter. Remove the trocar and inner sleeve from the sleeve, and drill the screw until all threads are in the bone (Fig 3.10.1-7a).
- If conventional Schanz screws are used, remove the trocar and drill the outer cortex of the bone with a 3.5 mm drill bit. Remove the drill bit and inner sleeve and insert a 5.0 mm screw mounted on the universal chuck with T-handle until all threads are in the bone.
- Check the position of the Schanz screw with the image inten-sifier.
- Repeat the process on the other side.
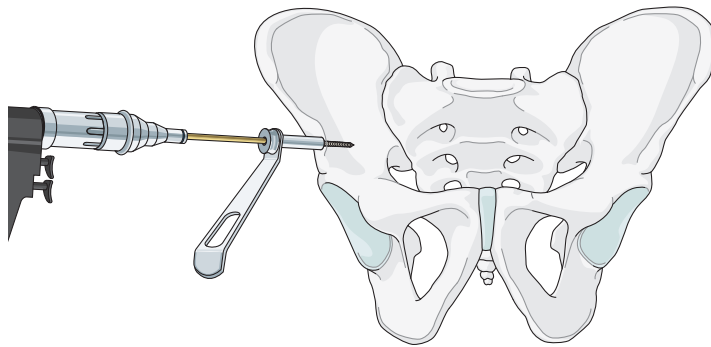
- Place a pin-to-bar clamp (self-holding clamp) on each Schanz screw, about 2 cm above the skin. If available magnetic resonance imaging safe clamps and carbon fiber rods should be used as they facilitate subsequent imaging.
- Attach a rod to each clamp and tighten the nuts by hand.
- Adjust the two rods to meet anteriorly in the midline distal to the pubic symphysis and connect them using a combination clamp (Fig 3.10.1-7b).
- Adjust the position of the pelvis under the guidance of the image intensifier and tighten all nuts with an 11 mm wrench.
- Dress the pin sites.

Further information is available on AO Teaching video 00115: Stabilization of the Anterior Pelvic Ring With an External Fixator; video 00122: Pelvis Pelvic Ring Instability Large External Fixator: Stabilization of the Pelvic Ring.
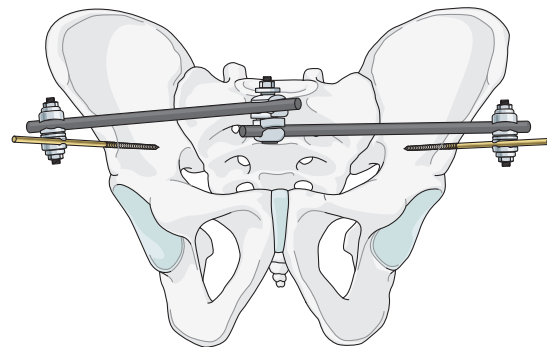
Fig 3.10.1-7a

Fig 3.10.1-7b

9 Specific perioperative care

- Ensure the patient is secured on the operating table.
- Take care of any pressure areas.

- Take care of the limbs that have frequently sustained serious but less urgent injuries and may require temporary splinting.

10 Specific postoperative care

- X-rays must be taken postoperatively to check and document the reduction and position of the Schanz screws, unless saved image intensifier views are adequate.
- Vigilant pin-track care is crucial to prevent infection. Initially, the pin sites must be cleaned and dressed daily.

- Plan any definitive internal fixation of the pelvis within 14 days if possible.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check that there is a selection of 11 mm carbon fiber (or stainless steel) rods of appropriate length and a selection of 5 mm Seldrill or conventional Schanz screws are available.

- Keep additional Schanz screws and clamps available.
- Make sure that external fixator clamps are not damaged and are correctly assembled.
- Be prepared for external fixation to be immediately followed by pelvic packing and/or laparotomy if external fixation fails to control the patient's blood loss.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Only the iliac crest Schanz screws should be inserted without an image intensifier. This technique should always be used in an emergency unless the surgeon is experienced in inserting supraacetabular pins.
- Iliac crest Schanz screws are not always secure. Two screws should always be used. A third screw makes having two secure ones more likely, particularly if the procedure has been performed without an image intensifier.

- When using either screw site be aware that pelvic ring disruption can distort the normal pelvic orientation and further complicate screw insertion.
- Do not insert Seldrill or Schanz screws using a power drill once the threads have engaged the bone. This increases the chances of the screw perforating one of the two tables of the iliac crest as it moves down between them, thus greatly weakening the screw fixation.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   AD Patel

3.10.2   Pelvic ring fracture with pubic symphysis diastasis(61-B1): stabilization with LC-DCP 4.5 narrow

Surgical management

- Fixation with LC-DCP 4.5 narrow

Alternative implants

- Symphyseal plate with coaxial combi-holes 3.5
- LCP narrow 4.5/5.0
- Recontruction plate 4.5

1   Introduction

- Disruption of the pubic symphysis can occur with both partial disruption of the posterior sacroiliac joint, allowing the pelvis to open, hinged on the remaining posterior sacroiliac ligaments (61-B1) or total disruption of the pelvic ring at the sacroiliac joint or through a sacral fracture (61-C1).
- Fixation of a pubic symphysis diastasis is indicated when there is more than 2.5 cm of separation.
- Establishing the amount of posterior instability is mandatory and requires a computed tomographic scan before surgery.
- When there is complete pelvic instability, the sacroiliac joint may need to be stabilized at the same time as the pubic symphysis plate is applied. This is not described here.
- Anterior pelvic instability can also occur through fractures of the superior and inferior pubic rami or acetabulum. The management of these injuries is not described here.

- Patients with pelvic ring injuries have often sustained other serious injuries, and management of these may take priority over fixation of the pubic symphysis.
- Patients should be treated with a pelvic binder until definitive surgery is performed.
- There is a high incidence of associated urethral damage with these fractures. Signs of this include blood at the external urethral meatus, bruising of the scrotum or penis, and or a high-riding prostate on rectal examination. If in doubt, a retrograde urethrogram should be performed before surgery to image the urethra. If a tear is confirmed, then a suprapubic urinary catheter must be inserted before operation.
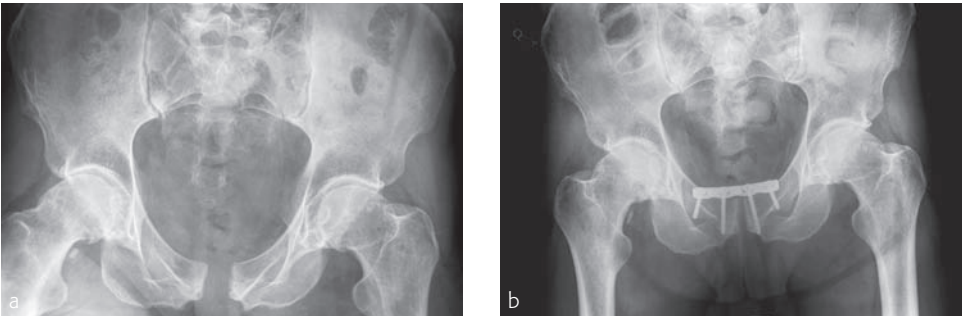
Fig 3.10.2-1a–b
a   Preoperative x-ray: B-type pelvic ring fracture showing rotational instability.
b   Postoperative x-ray: stabilization using LC-DCP 4.5 narrow.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implants to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Basic instrument and screw set 4.5/6.5 mm
- LC-DCP 4.5 instrument and implant set
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- A radiolucent pelvic table to permit AP, inlet, and outlet images are preferred. If not available, use a standard operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

Author   AD Patel

3   Anesthesia

- This procedure is performed with the patient under general anesthesia, including muscle relaxation to relax rectus abdomonis.
- Epidural anesthesia performed before or after surgery (depending on the ability to move the patient) is helpful for postoperative pain control.

- A urethral or suprapubic urinary catheter (depending on the presence of a urethral tear) must be in place before surgery starts to keep the bladder empty.

4   Patient and x-ray positioning

- Place the patient in the supine position with a pillow under the knees and the legs kept tied together with the legs in internal rotation (Fig 3.10.2-2).
- Be careful when transferring the patient to minimize movement of the pelvic ring fracture.
- Make sure other injuries are not compromised by positioning the patient.
- Pressure areas should be protected.
- Ideally, the table should allow for image intensifier access to the pelvis, although this is not always possible.
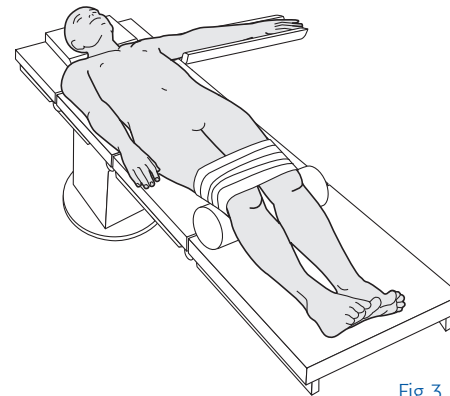
Fig 3.10.2-2

5 Skin disinfecting and draping

- Pubic shaving is required and should be done immediately before surgery.
- Disinfect the exposed area from knees to mid thorax to include the whole abdomen with the appropriate antiseptic (Fig 3.10.2-3a).
- Draping should allow for the possibility of a subsequent laparotomy or pelvic-packing procedure (Fig 3.10.2-3b).
- Drape the image intensifier.
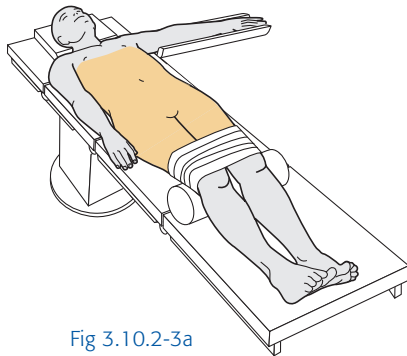
Fig 3.10.2-3a
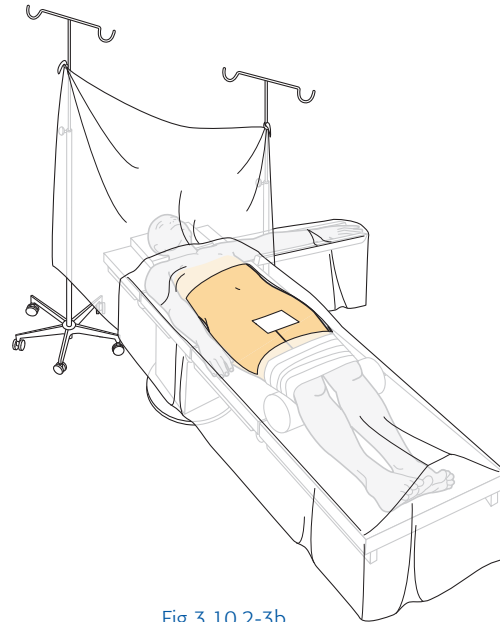
Fig 3.10.2-3b

6 Operating room set-up

- The surgeon stands on one side of the patient.
- The assistant stands opposite the surgeon.
- The ORP sets up adjacent to the surgeon.
- The image intensifier comes in from the side opposite the surgeon.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.10.2-4).

Fig 3.10.2-4

Author   AD Patel
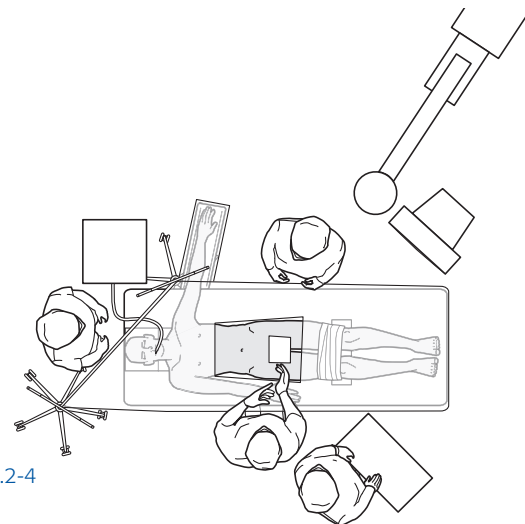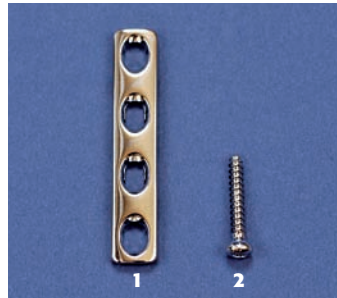
7   Instrumentation

Fig 3.10.2-5a   Implants
1.   LC-DCP 4.5 narrow, 4 holes
2.   Cortex screw 4.5 mm
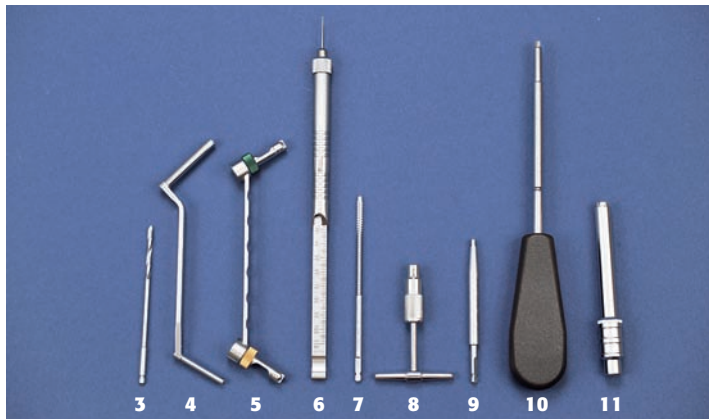
Fig 3.10.2-5b   Instruments for fracture fixation with LC-DCP 4.5
3.   Drill bit 3.2 mm
4.   Double drill sleeve 4.5/3.2 mm
5.   LC-DCP drill sleeve 4.5 mm
6.   Depth gauge
7.   Tap 4.5 mm for cortex screws
8.   T-handle
9.   Screwdriver shaft
10. Screwdriver with holding sleeve
11. Holding sleeve, large

Fig 3.10.2-5c   Instruments for reduction and contouring
12. Bending press
13. Reduction forceps with points, large
14. Bending iron (two)

8 Procedure and technique—step-by-step

- Make a 5–8 cm curved skin incision just above the pubic symphysis following the natural line of the skin creases. Deepen the incision through the subcutaneous fat to expose the rectus sheath. Divide the sheath in the line of the skin incision.
- One rectus muscle is nearly always detached from its insertion into the pubis. Retract the two rectus muscles apart.
- Partially detach the rectus from the pubic tubercle and superior pubic ramus using a combination of sharp and blunt dissection, exposing the pubic tubercle and the medial part of the superior pubic ramus on both sides.
- Using a large pointed reduction forceps reduce the symphysis pubis separation (Fig 3.10.2-6a). Manual compression of the pelvis by the assistant makes this a lot easier.
- Position a 4-hole LC-DCP 4.5 narrow to allow two 4.5 mm cortex screws to be inserted on either side of the symphysis.

- Place the plate across the superior surface of the reduced symphysis.
- Using the neutral (green) drill guide with the arrow pointing toward the fracture, drill a 3.2 mm hole into the body of the pubis, being careful that the drill bit does not penetrate the inner wall of the pubis as this can cause bladder damage.
- Measure and tap the hole and insert a 4.5 mm cortex screw of appropriate length.
- Repeat for the hole on the other side of the symphysis and then for the two remaining unfilled holes (Fig 3.10.2-6b–c).
- Check the position of the plate and screws and document with the image intensifier. AP and inlet and outlet views should be obtained.
- Close the wound.

Further information is available on AO Teaching video 53027: Pelvic Fixations—Symphysis Pubis and Pubic Rami.
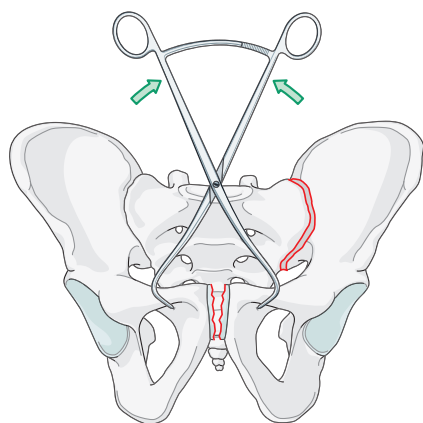
Fig 3.10.2-6a
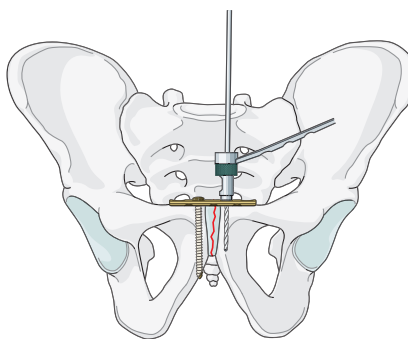
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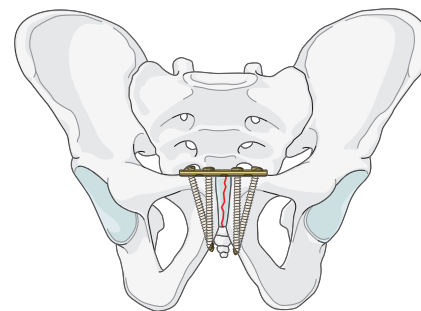
Fig 3.10.2-6c

Author   AD Patel

9   Specific perioperative care

- Ensure the patient is secured on the operating table.
- Take care of any pressure areas.

- Be careful of the limbs that have frequently sustained serious but less urgent injuries and may require temporary splinting.
- Be prepared for external fixator removal.

10   Specific postoperative care

- X-rays must be taken postoperatively to check and document the reduction and position of the plate and screws, unless saved image intensifier views are adequate.

- Patient weight bearing is at the surgeon's discretion, but a minimum of 3 months nonweight bearing is common.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.

- Be prepared for a laparatomy in case of unexpected complications.
- Prepare instruments for removal of the external fixator.
- Document and reorder all implants used.

12   Surgeons—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Make sure the degree of pelvic instability is known before starting surgery.
- Be very careful not to penetrate the posterior cortex of the pubis with the drill or screw, as this can cause bladder injury.
- Conventional LC-DCP and LCP plates used in this way are prone to breakage because of the high forces across the pubic symphysis.

- For this reason some surgeons prefer to use stronger alternatives, such as the new symphyseal plate with coaxial combi-holes 3.5.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.11　Proximal femoral fractures

Authors   Malcolm Smith, Matthew Porteous

3.11   Proximal femoral fractures

Implants and surgical technique	Cases
■ Cannulated screws 7.3 mm	■ Intracapsular femoral neck fractures (31-B1)
■ Dynamic hip screw (DHS)	■ Extracapsular trochanteric femoral fractures (31-A2)
■ Proximal femoral nail antirotation (PFNA)	■ Extracapsular trochanteric femoral fractures (31-A2)
■ Proximal femoral nail (PFN)	■ Subtrochanteric femoral fractures (32-A2)
■ 95° Condylar blade plate	■ Special subtrochanteric femoral fracture (32-B2)

Introduction

■ The Müller AO/OTA Classification divides proximal femoral fractures in three groups:
  – type 31-A: extracapsular trochanteric fractures
  – type 31-B: intracapsular femoral neck fractures
  – type 31-C: intracapsular femoral head fractures (not included in this chapter)

■ Subtrochanteric fractures are classified as diaphyseal fractures in the subtrochanteric region 32-A1-3.1 and 32-B1-3.1 with the subgroup .1 identifying the fracture as subtrochanteric. 32-C fractures are not identified as a separate group.

■ Subtrochanteric fractures are more difficult to treat than more distal diaphyseal fractures because of the very high loads put on implants used in this area.

■ Proximal femoral fractures occur most frequently in the elderly who have osteoporosis and other significant comorbidities. The incidence of these fractures is increasing rapidly and they cause considerable personal and socioeconomic problems.

■ Displaced intracapsular fractures in the elderly are usually treated by femoral head or total hip replacement. A further description of this will not appear in this chapter.

■ Similar fracture patterns are seen in younger patients, but generally follow high-energy trauma and are often accompanied by other significant injuries.

■ The local anatomy of the femoral neck, and especially of the subtrochanteric region, creates a difficult biomechanical environment. Implants carry high loads and loss of fixation, and implant failure are relatively common complications.

■ Undisplaced femoral neck fractures and those with valgus impaction can be treated with screws alone.

■ Fractures in the trochanteric region can be divided into those which are stable after fixation (31-A1) and those which are unstable (31-A2, 31-A3). Stability depends on whether the medial side of the bone (calcar) is in contact once the fracture has been reduced. Stable fractures can be fixed with an extramedullary implant, most commonly the DHS. Unstable fractures require more stability, and intramedullary implants, such as the proximal femoral nail antirotation (PFNA) or the proximal femoral nail (PFN), are used. The trochanteric stabilization plate (TSP) can be added if a DHS is used in these fractures.

■ Subtrochanteric fractures and those trochanteric fractures with an extension into the subtrochanteric region are generally treated by intramedullary devices for biomechanical reasons.

■ The angled blade plate and the dynamic condylar screw (DCS) are used in special situations.

Müller AO/OTA Classification—proximal femur

| 31-A1 | 31-A2 | 31-A3 | 31-B1 | 31-B2 | 31-B3 | 31-C1 | 31-C2 | 31-C3 |

**31-A   extraarticular fracture,
trochanteric area**
31-A1   pertrochanteric simple
31-A2   pertrochanteric multifragmentary
31-A3   intertrochanteric

31-B   extraarticular fracture, neck
31-B1   subcapital, with slight displacement
31-B2   transcervical
31-B3   subcapital, displaced, nonimpacted

31-C   articular fracture, head
31-C1   split (Pipkin)
31-C2   with depression
31-C3   with neck fracture

Authors   Malcolm Smith, Matthew Porteous

3.11.1   Intracapsular femoral neck fractures (31-B1): stabilization with 7.3 mm cannulated screws

Surgical management

- Stabilization with 7.3 mm cannulated screws

Alternative implants

- 6.5 mm cannulated screws
- 6.5 mm cancellous bone screws
- DHS with additional 6.5 mm cancellous bone screw

1   Introduction
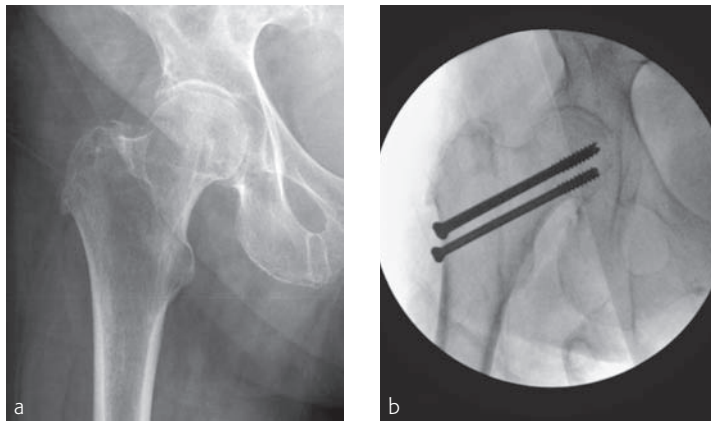
Fig 3.11.1-1a–b
a   Preoperative x-ray: impacted intracapsular femoral neck fracture.
b   Postoperative x-ray: stabilization of fracture with three cannulated screws.

- Intracapsular fractures occur through the femoral neck.
- Displaced fractures may interrupt femoral head blood supply and therefore in younger patients require reduction and fixation. A femoral head or total hip replacement may be preferred in the elderly.
- Minimally or undisplaced fractures should be treated by surgical stabilization as they tend to collapse into varus.
- The easiest method of stabilization is the insertion of three parallel screws through a small lateral incision under x-ray control to allow subsequent controlled impaction of the fracture.
- Results are good if the reduction is stable and screws are placed along the walls of the neck and not in the center (where the bone stock is not as good).
- Major failure usually requires a total hip replacement.
- Elderly patients with significant comorbidities and valgus impaction can be treated nonoperatively but are at significant risk of further displacement and may then need a hemiarthroplasty or total hip replacement.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- 7.3 mm cannulated screw set
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Fracture table with extensions or radiolucent table
- Positioning accessories
- Image intensifier
- X-ray protection devices for personnel and patient

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- With the patient anesthetized, reconfigure the table as, or transfer the patient to, a fracture table.
- Mount a padded perineal post on the injured side and fit side supports.
- Apply straight traction to the injured leg.
- Abduct and flex the opposite leg and place it out of the way in a gynecological leg holder (Fig 3.11.1-2a). Hip flexion usually allows greater abduction and the use of this support allows good access for the image intensifier. Alternatively, place the opposite leg in a padded boot and abduct it (Fig 3.11.1-2b). Lock all table joints.
- Fix or place the padded ipsilateral arm across the chest so it is out of the way.
- Take great care with the soft tissues and skin pressure points, particularly in the elderly.
- Adjust the operating table to an appropriate height.
- Place the image intensifier obliquely between the spread legs and maneuver the C-arm over the injured hip for an AP view (Fig 3.11.1-3a).
- Swivel the C-arm approximately 90° for a lateral (axial) view (Fig 3.11.1-3b).
- Ensure that the image intensifier can obtain AP and lateral (axial) views of the hip by simple rotation of the C-arm. Do not prepare and drape the patient until good-quality x-rays are obtainable.

Authors   Malcolm Smith, Matthew Porteous

- Unlock the table joints, reduce the fracture (usually by traction, adduction, internal rotation), and then lock all table joints.
- The surgeon must be satisfied with the reduction before the patient is prepared for surgery.
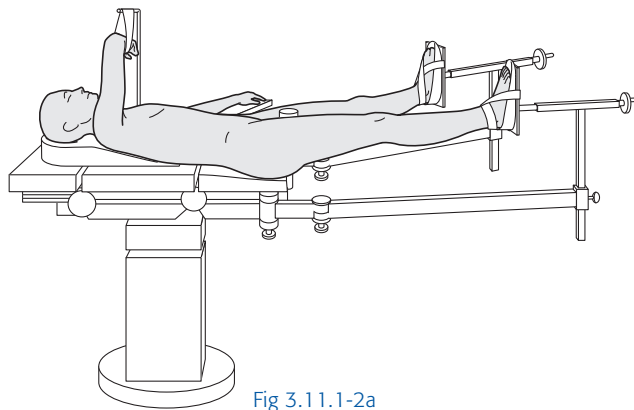
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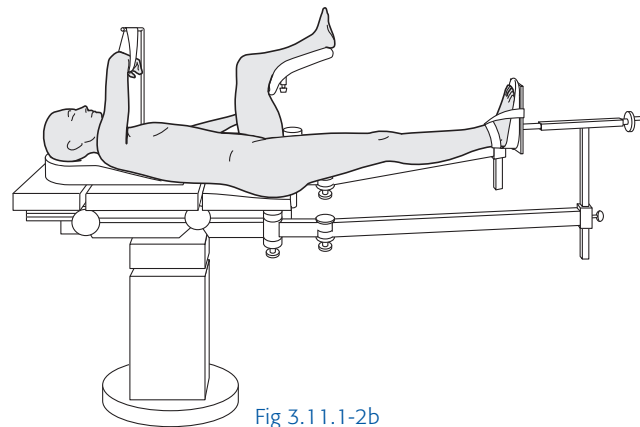
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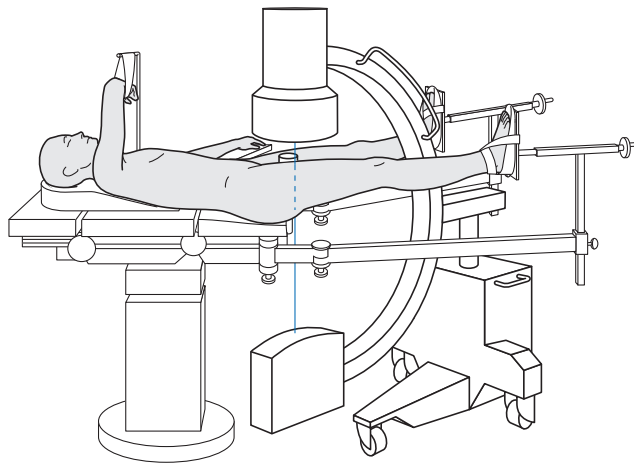
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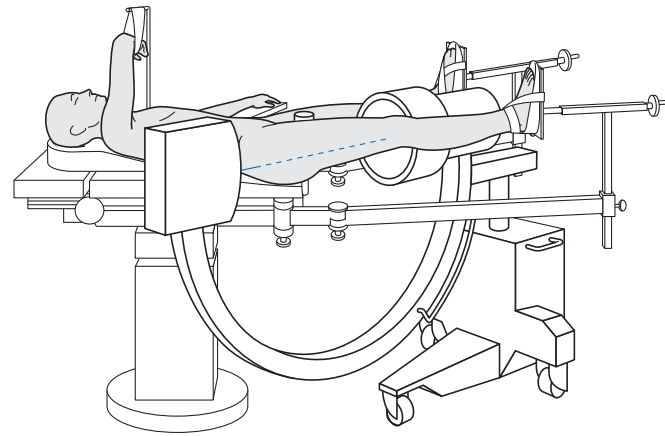
Fig 3.11.1-3b

5 Skin disinfecting and draping

- Disinfect the exposed area with the appropriate antiseptic (Fig 3.11.1-4a).
- Drape the limb. A single-use drape (curtain) may be used (Fig 3.11.1-4b).

- The image intensifier remains on the nonsterile side of the drape. Sterility must be maintained particularly when taking lateral (axial) x-rays.
- If traditional drapes are used, ensure a waterproof environment for the operative site.
- Drape the image intensifier.
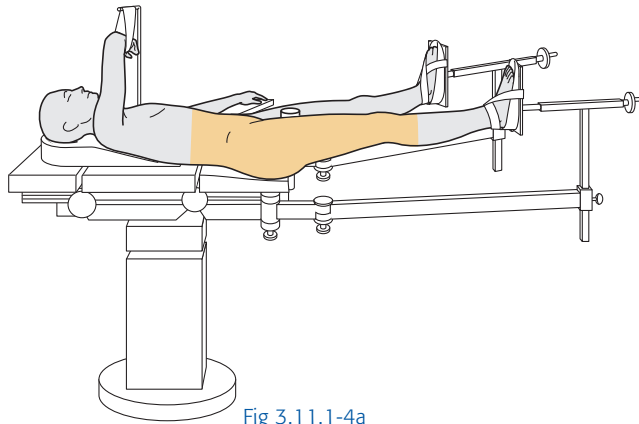
Fig 3.11.1-4a
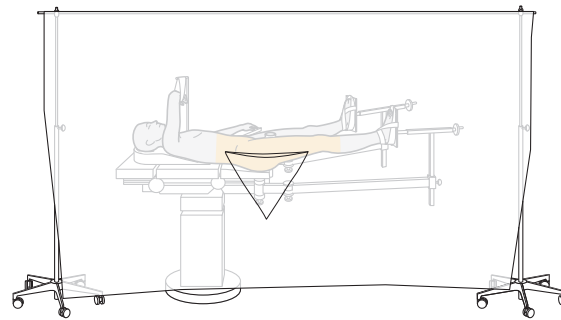
Fig 3.11.1-4b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- Position the image intensifier on the opposite side of the injury between the patient's legs.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.11.1-5).

Fig 3.11.1-5

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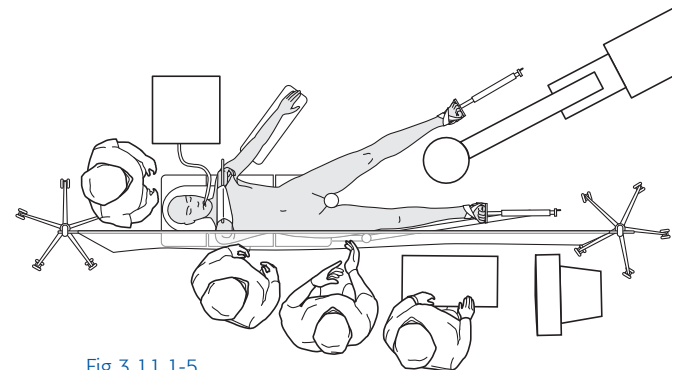
7   Instrumentation

Fig 3.11.1-6a   Implants
1.   Cannulated screw 7.3 mm, long thread 32 mm
2.   Cannulated screw 7.3 mm, short thread 16 mm
3.   Washers
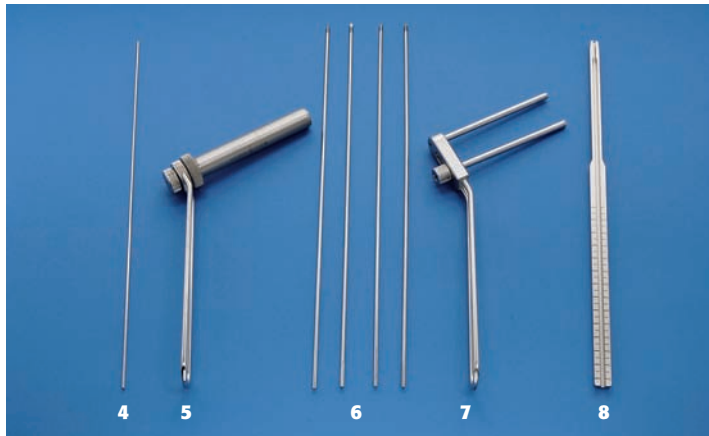
Fig 3.11.1-6b   Instruments for guide wire insertion
4.   K-wire 2.0 mm, long
5.   Protection sleeve assembly (3 parts)
6.   Threaded guide wires 2.8 mm
7.   Adjustable parallel guide for guide wires 2.8 mm
8.   Measuring device for 2.0 mm and 2.8 mm guide wires

Fig 3.11.1-6c   Instruments for screw insertion
9.   Cannulated drill bit 5.0 mm
10.   Cannulated tap
11.   Cannulated countersink
12.   Hexagonal screwdriver for final tightening or removal of screws
13.   Cannulated hexagonal screwdriver

8 Procedure and technique—step-by-step

- Make a small incision on the lateral side of the proximal femur in line with the femoral neck.
- Determine the femoral neck anteversion with a K-wire. Slide a long K-wire, blunt end first, along the anterior surface of the femoral neck.
- Using the protection sleeve and guide, insert a 2.8 mm threaded guide wire into the femoral head from the lateral cortex, starting just above the level of the lesser trochanter. The wire should pass just along the calcar parallel to the anteversion K-wire. Ensure perfect positioning by using x-ray control in both planes. Remove the anteversion wire (Fig 3.11.1-7a).
- Using the adjustable parallel guide insert two further parallel guide wires above the first wire into the femoral neck and head. One wire is more anterior to the original wire and the other is more posterior. All three should end 1 cm from the articular surface in both planes. Alternatively, this can be done freehand. These guide wires will determine the final position of the three screws (Fig 3.11.1-7b).
- Remove the trocar and drill sleeve and measure the required screw lengths with the direct measuring device (Fig 3.11.1-7c).

- Using the 5.0 mm cannulated drill bit and tissue protector over each wire, broach the lateral cortex. This is sufficient in poor-quality bone, but in good-quality bone the drill bit should be advanced to within 1 cm of the tip of the guide wire. If the guide wire comes out when the drill bit is withdrawn, carefully reinsert it ensuring that it returns to its original position by using x-ray control.
- If the bone is dense, tap the lateral cortex.
- Insert the selected screws, short or long threaded with the cannulated screwdriver. Ensure each thread crosses beyond the fracture into the head fragment (Fig 3.11.1-7d).
- Washers should be used in elderly patients, as their cortex is too weak to countersink.
- Check that the guide wires do not advance into the pelvis during drilling and screw insertion under the guidance of the image intensifier.
- Remove the guide wires and fully tighten the screws with the conventional screwdriver (Fig 3.11.1-7e).
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 00104: The 7.3 mm Cannulated Screw: Femoral Neck Fracture.

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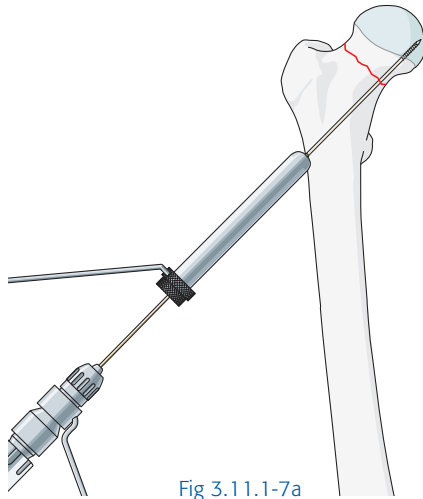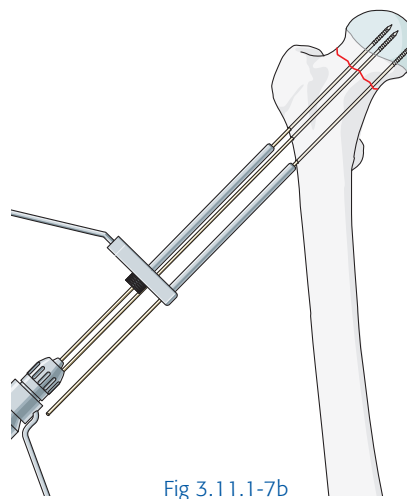
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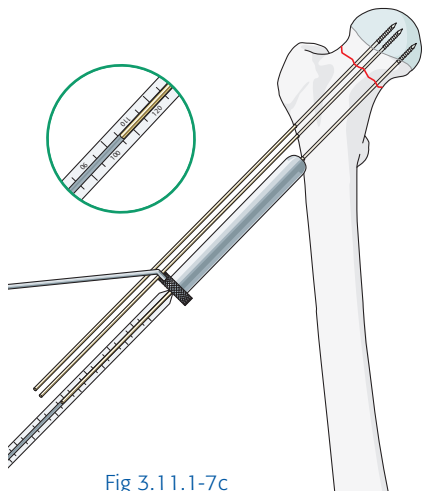
Fig 3.11.1-7b

Fig 3.11.1-7c
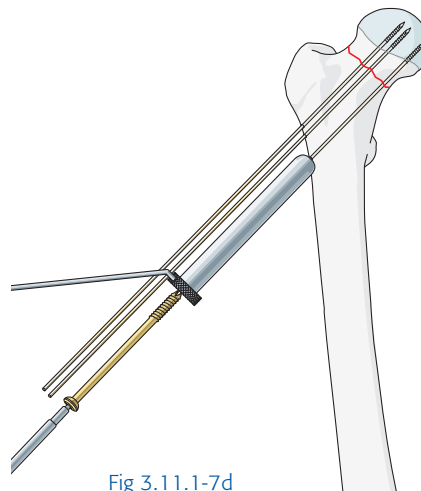
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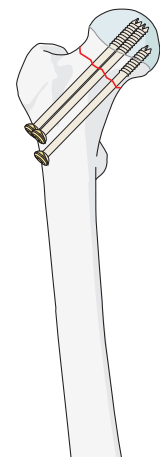
Fig 3.11.1-7e

9 Specific perioperative care

- Be careful with the pressure areas (especially in the elderly).
- Confirm that the patient is secured on the fracture table and the fracture is well reduced.
- Maintain sterility as the image intensifier is rotated around the surgical field.

- Check that the guide wires are not advanced into the pelvis during drilling and screw insertion.
- Make sure that sharp instruments do not penetrate the plastic exclusion drape.

10 Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the implant, unless adequate hard copies have been taken with the image intensifier.
- The fixation should allow safe general lifting and handling of the patient for nursing.

- Patients should be mobilized immediately. Limited weight bearing for 6 weeks is advised for younger patients; however this is not always possible in the elderly.
- In the elderly rehabilitation is often limited by other medical conditions, which may be aggravated by lack of understanding and compliance.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Make sure that new guide wires of the correct size are used each time. Damaged wires may bind to the drill or to the screw during insertion and may be accidentally advanced into the pelvis.

- Always have additional correct guide wires available.
- Check the screw length and select the required thread length.
- At the end of the procedure check that the guide wire is not jammed in the drill bit.
- Flush and preclean (stylet, brush) all cannulated instruments carefully.
- Discard the guide wires after use.
- Document and reorder all implants used.

Authors   Malcolm Smith, Matthew Porteous

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Good patient set-up and fracture reduction is essential: the fracture should be placed in a stable position with the hip in a little valgus (traction) before scrubbing up. Open reduction may be required to obtain a satisfactory reduction especially in younger patients.
- Obtain clear x-rays in both planes to allow accurate placement of guide wires and screws: the first over the calcar, two more above one in an anterior and one in a posterior position. If the screws are not parallel, they will impede controlled collapse of the fracture and, therefore, healing.

- Try to avoid repetitive guide wire insertions. The unfilled guide wire holes weaken the lateral cortex and may result in a subtrochanteric fracture occurring when the patient mobilizes. Similar fractures may occur if the screws are inserted below the level of the lesser trochanter.
- Regularly check the guide wire position during drilling and screw insertion.
- The screw threads must cross beyond the fracture line so as to allow compression at the fracture site.
- Use a noncannulated screwdriver for final tightening or removal of the screws.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Authors   Malcolm Smith, Matthew Porteous

3.11.2   Extracapsular trochanteric femoral fractures (31-A2): stabilization with dynamic hip screw (DHS)

Surgical management

- Stabilization with dynamic hip screw (DHS)

Alternative implants

- Proximal femoral nail antirotation (PFNA)
- Proximal femoral nail (PFN)

1   Introduction

- Extracapsular fractures occur around the base of the femoral neck in the trochanteric area.
- They do not interrupt the blood supply of the femoral head, but create a fracture pattern in which the femoral neck tends to collapse into varus.
- The DHS is designed as an extramedullary implant to stabilize these trochanteric fractures.
- A large screw is inserted into the femoral neck and a fixed-angled, plate-barrel device is then slid over the screw and fixed to the femoral shaft; the device facilitates fracture healing by allowing compression of the fracture to occur as the patient starts to bear weight, since the screw can slide back into the barrel.
- Results are good provided the DHS is correctly used in fractures of an appropriate type (31-A1, 31-A2).
- Possible rotation of the head around the DHS can be avoided by the insertion of an additional 6.5 mm cancellous bone screw.
- For a more unstable fracture pattern (31-A2), a trochanter stabilization plate (TSP) can be added to prevent a medial shift of the shaft during fracture healing.
- Problems occur if the fracture is badly reduced, the implant is badly placed, or the sliding mechanism is blocked. Screw cut-out may then occur.
- Weight bearing depends on the fracture type; simple fractures can be loaded immediately.
- The DHS is no longer indicated for reversed oblique (31-A3) or subtrochanteric fractures.
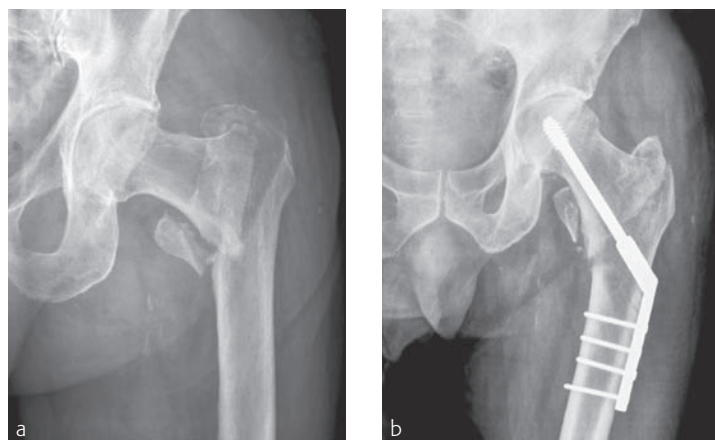
Fig 3.11.2-1a–b
a   Preoperative x-ray: extracapsular proximal femeral fracture.
b   Postoperative x-ray: stabilization with dynamic hip screw (DHS).

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- DHS instrument and implant set
- Basic instrument and screw set 4.5/6.5
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Fracture table with extensions or radiolucent table
- Positioning accessories
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- With the patient anesthetized, reconfigure the table as, or transfer the patient to, a fracture table.
- Mount a padded perineal post on the injured side and fit side supports.
- Apply straight traction to the injured leg.
- Abduct and flex the opposite leg and place it out of the way in a gynecological leg holder (Fig 3.11.2-2a). Hip flexion usually allows greater abduction and the use of this support allows good access for the image intensifier. Alternatively, place the opposite leg in a padded boot and abduct it (Fig 3.11.2-2b). Lock all table joints.
- Fix or place the padded ipsilateral arm across the chest so it is out of the way.
- Exercise great care with the soft tissues and skin pressure points, particularly in the elderly.
- Adjust the operating table to an appropriate height.
- Place the image intensifier obliquely between the spread legs and maneuver the C-arm over the injured hip for an AP view (Fig 3.11.2-3a).
- Swivel the C-arm approximately 90° for a lateral (axial) view (Fig 3.11.2-3b).
- Ensure that the image intensifier can obtain AP and lateral (axial) views of the hip by simple rotation of the C-arm. Do not prepare and drape until good-quality x-rays are obtainable.
- Unlock the table joints, reduce the fracture (usually by traction, adduction, internal rotation), and then lock all table joints.
- The surgeon must be satisfied with the reduction before the patient is prepared for surgery.

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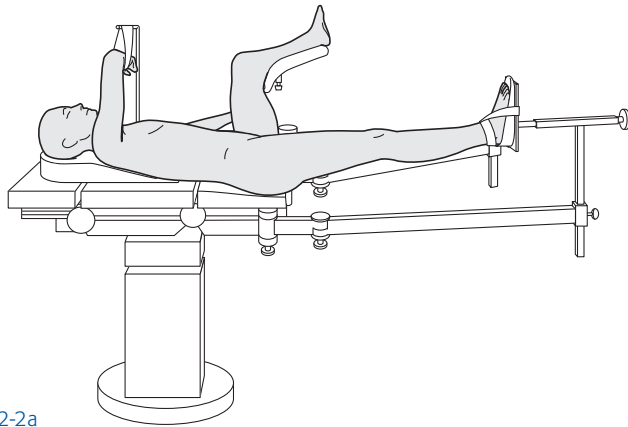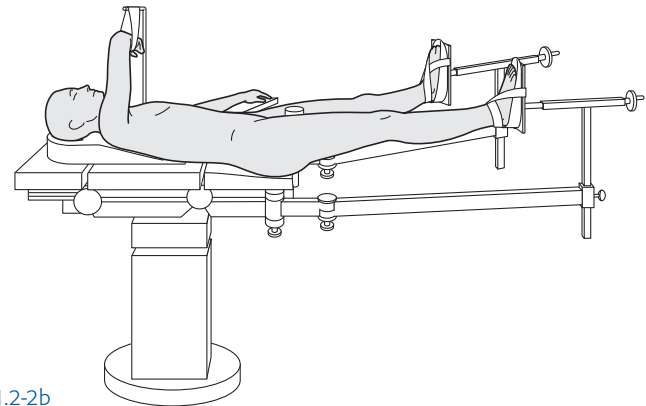
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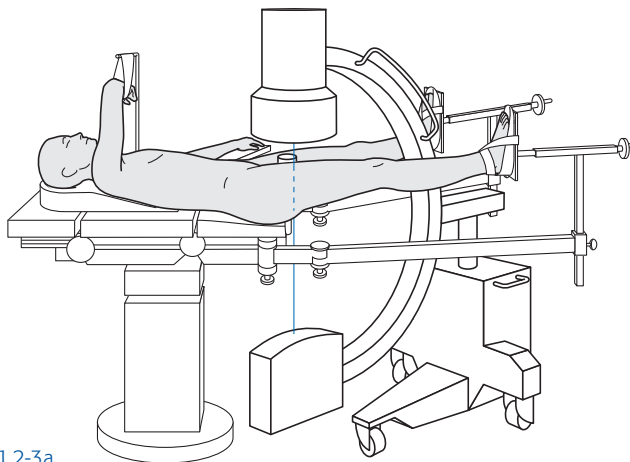
Fig 3.11.2-2b

Fig 3.11.2-3a
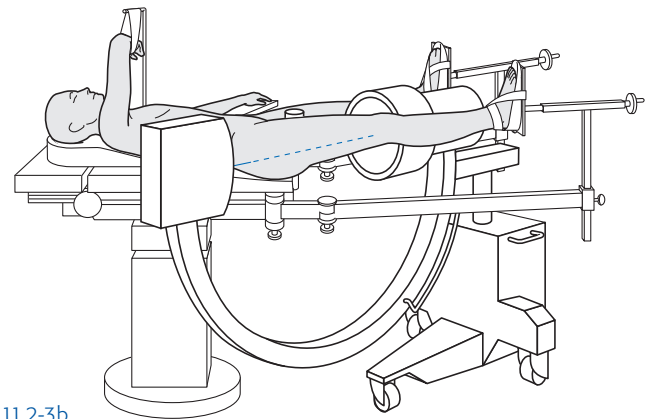
Fig 3.11.2-3b

5 Skin disinfecting and draping

- Disinfect the exposed area with the appropriate antiseptic (Fig 3.11.2-4a).
- Drape the limb. A single-use exclusion drape (curtain) may be used (Fig 3.11.2-4b).
- The image intensifier remains on the nonsterile side of the drape.

Sterility must be maintained particularly when taking lateral (axial) x-rays.

- If traditional drapes are used, ensure a waterproof environment for the operative site.
- Drape the image intensifier.
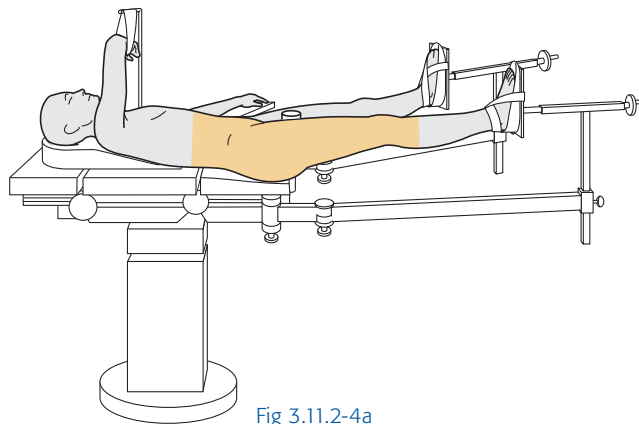
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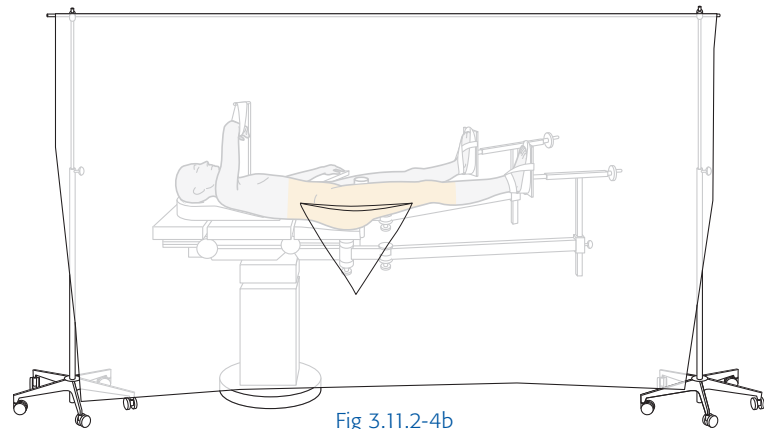
Fig 3.11.2-4b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- Position the image intensifier on the opposite side of the injury between the patient's legs.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.11.2-5).

Fig 3.11.2-5

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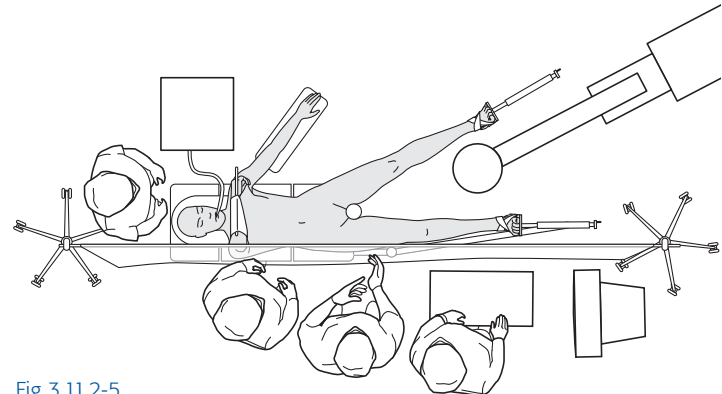
7   Instrumentation

Fig 3.11.2-6a   Implants
1.   DHS screw
2.   DHS plate
3.   Cortex screw 4.5 mm
4.   DHS compression screw

Fig 3.11.2-6b   Implants
5.   DHS trochanter stabilization plate
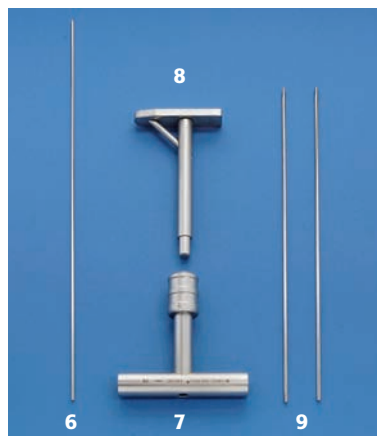
Fig 3.11.2-6c   Instruments for guide wire insertion
6.   K-wire 2.0 mm, long
7.   T-handle with coupling
8.   DHS angled guide (care for correct angle, eg, 135°)
9.   DHS threaded guide wires 2.5 mm

Fig 3.11.2-6d Instruments for measuring, reaming, and tapping DHS screw
10. Direct measuring device
11. DHS triple reamer, long barrel
12. DHS tap, to be used with T-handle (7)
13. DHS centering sleeve

Fig 3.11.2-6e Instruments for screw and plate insertion
14. DHS insertion wrench for one-step insertion
15. Coupling screw
16. DHS centering sleeve
17. DHS impactor
18. Hammer

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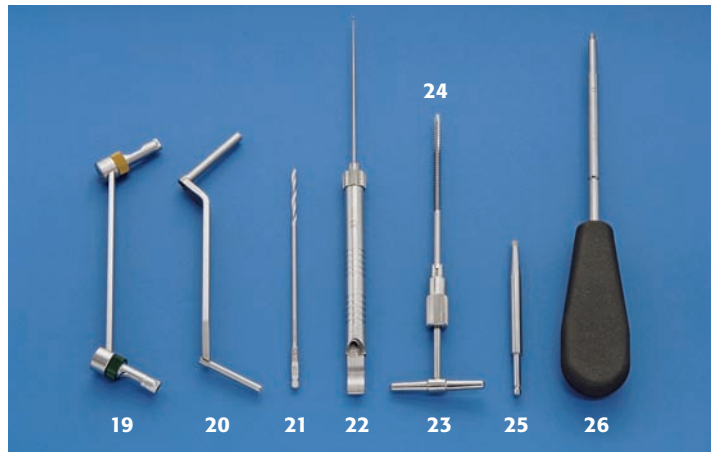
Fig 3.11.2-6f   Instruments for plate fixation
19.   DCP drill guide 4.5 mm
20.   Double drill guide 3.2/4.5 mm
21.   Drill bit 3.2 mm
22.   Depth gauge
23.   T-handle
24.   Tap for cortex screws 4.5 mm
25.   Screwdriver shaft
26.   Screwdriver
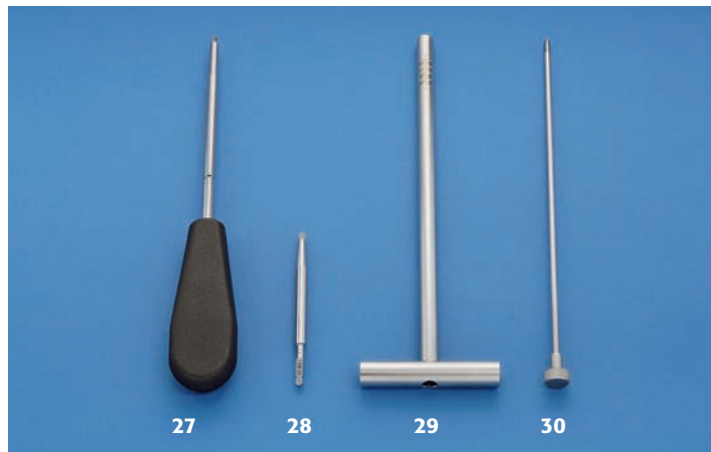
Fig 3.11.2-6g   Instruments for implant removal
27.   Screwdriver
28.   Screwdriver shaft
29.   DHS wrench for removal
30.   Coupling screw

8 Procedure and technique—step-by-step

- Make a longitudinal incision on the lateral aspect of the thigh starting just proximal to the femoral neck and extending distally. The length of the incision depends on the size of the side plate to be used.
- The fascia lata is incised and the vastus lateralis split or displaced superiorly.
- Determine the anteversion with a K-wire inserted blunt end first, over the front of the femoral neck (Fig 3.11.2-7a).
- Hold the selected-angled guide (usually 135°) in a T-handle firmly against the femur and insert a 2.5 mm threaded guide wire centrally into the femoral neck and head under x-ray control in both planes. The wire must be parallel to the anteversion wire (Fig 3.11.2-7b).

- The tip of the guide wire should end in the subchondral bone in the exact center of the femoral head in both planes.
- Be careful not to penetrate the hip joint with the guide wire.
- Remove the anteversion K-wire.
- Measure the length of the guide wire with the direct measuring device (Fig 3.11.2-7c).
- Set the triple reamer to 10 mm shorter than the measured length and drill the hole over the guide wire (Fig 3.11.2-7d).
- The guide wire may jam and come out with the reamer. If so, carefully and accurately replace the wire using an inverted screw with sleeve for guidance. Ensure that the replaced guide wire is in the correct position using the image intensifier.
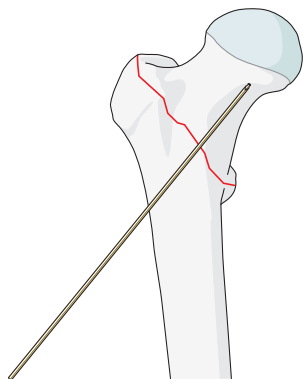
Fig 3.11.2-7a
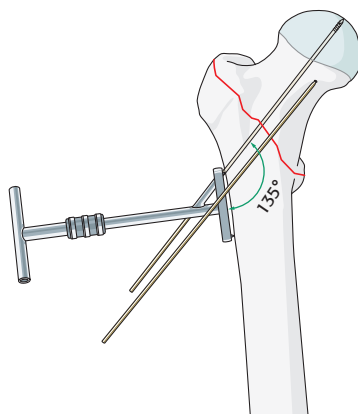
Fig 3.11.2-7b

Fig 3.11.2-7c

Fig 3.11.2-7d

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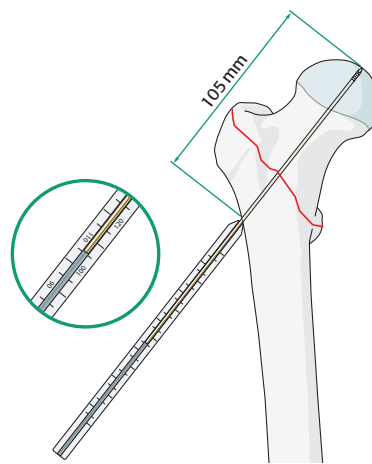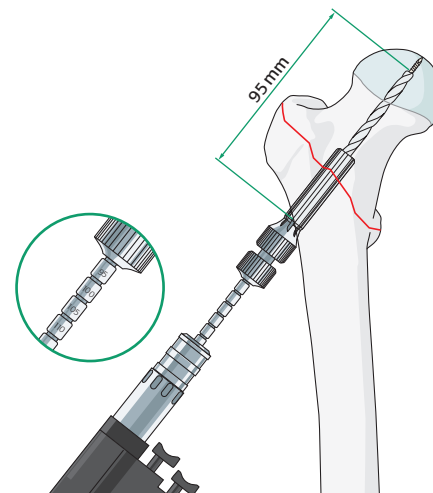
- Tapping is normally only required in young patients with dense bone (Fig 3.11.2-7e).
- Assemble the plate, screw, and sleeve: insert the coupling screw into the wrench and slide the appropriate plate onto the wrench. Connect the coupling screw with the DHS screw, and finally attach the centering sleeve.
- Insert the screw over the guide wire until mark zero is shown in the sleeve. The screw tip should end 10 mm from the joint surface. Check that the guide wire does not jam and become advanced into the pelvis during screw insertion (Fig 3.11.2-7f).
- The handle must finish parallel to the long axis of the femur so that the flats on the DHS screw match those inside the barrel of the plate (the flats provide rotational stability of the screw plate) (Fig 3.11.2-7g).
- Check the screw position in both planes.
- Remove the guide wire.

- Impact the plate into position (Fig 3.11.2-7h). Remove centering sleeve and inserter.
- Fix the plate to the femoral shaft with 4.5 mm cortex screws. Drill a 3.2 mm hole using the DCP drill sleeve in neutral position (green), measure the depth, tap the hole with a 4.5 mm tap and protection sleeve, and insert the appropriate length screw (Fig 3.11.2-7i–j).
- Tighten all screws once more.
- The DHS compression screw must not be used in osteoporotic patients as this will cause the screw to loosen its grip in the femoral head. Compression is obtained when the patient bears weight and the fracture impacts. If the DHS compression is used to obtain compression at the time of surgery, only use it in patients with good bone stock, relax the traction before tightening the screw, and remove the screw after use.
- Take and save copies of final x-rays in both planes.
- Close the wound.
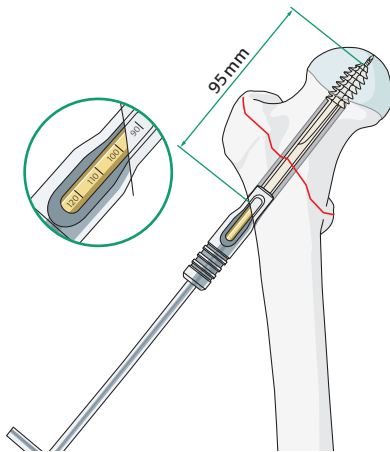
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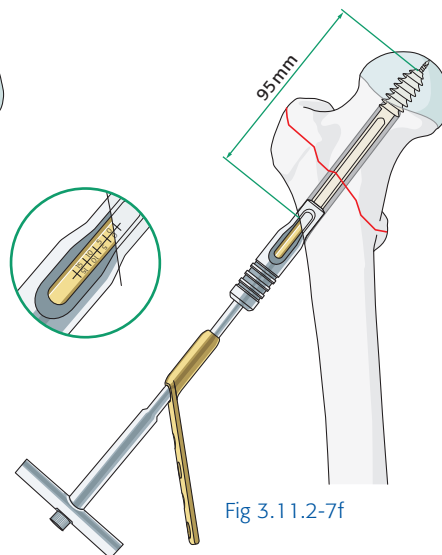
Fig 3.11.2-7f
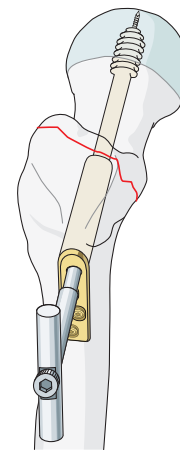
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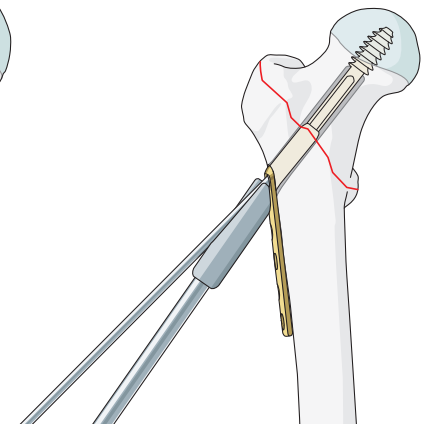
Fig 3.11.2-7h

Trochanter stabilization plate (TSP)
- Adding this plate onto the DHS plate may improve stability in unstable fractures (31-A2).
- The DHS is applied in the normal way and fixed to the femoral shaft with one cortex screw only.
- The TSP is then placed over the DHS plate (Fig 3.11.2-8a). The remaining cortex screws are then used to secure both plates together.

- A so-called antirotation screw (cancellous bone screw, partially threaded 6.5 mm) must be passed through the plate into the femoral head.
- Under the guidance of the image intensifier drill a 3.2 mm hole into the femoral head, proximal and parallel to the DHS screw (Fig 3.11.2-8b). Measure the depth, tap the outer cortex with a 6.5 mm tap, and insert a partially threaded 6.5 mm cancellous bone screw (Fig 3.11.2-8c).
- Additional screws or wires may be used through the top plate holes to fix fragments of the greater trochanter if required.

Further information is available on AO Teaching video 20156: Dynamic Hip Screw (DHS).
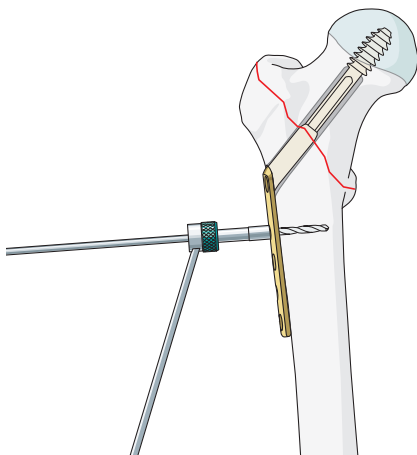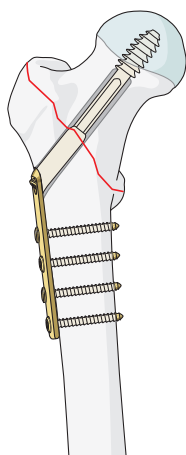
| Fig 3.11.2-7i | Fig 3.11.2-7j | Fig 3.11.2-8a | Fig 3.11.2-8b | Fig 3.11.2-8c |
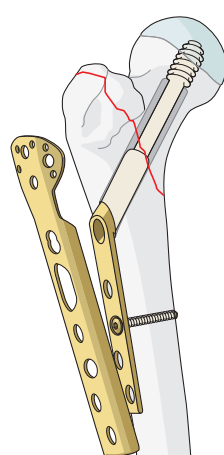
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9   Specific perioperative care

- Be careful with pressure areas, especially in the elderly.
- Confirm that the patient is secured on the fracture table and that the fracture is reduced.
- Maintain sterility as the image intensifier is rotated around the surgical field.
- Check that the guide wire is not advanced into the pelvis during drilling and screw insertion.
- Make sure that sharp instruments do not penetrate the plastic exclusion drape.

10   Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the implant unless adequate hard copies have been taken with the image intensifier.
- The fixation should allow safe general lifting and handling of the patient for nursing.
- Most patients are allowed to fully bear weight immediately.
- In the elderly, rehabilitation is often limited by other medical conditions.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Make sure that a new 2.5 mm guide wire of correct length is used, as damaged wires may bind to the drill or to the screw during insertion and may be accidentally advanced into the pelvis.
- Always have additional correct guide wires available.
- Do not confuse the different triple reamers: DHS reamer (short and long barrel version) and DCS reamer.
- Confirm the agreed measurement for the reamer setting with the surgeon.
- Confirm the screw length before assembling it.
- Ensure the correct angle for the plate.
- If a short screw length is required (< 80 mm), use a short barrel DHS.
- At the end of the procedure check that the guide wire is not jammed in the drill bit.
- Flush the cannulated triple reamer carefully.
- Discard the guide wire after use.
- Be prepared for application of different types of screws including the use of a TSP.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Good patient set-up and fracture reduction is essential: the fracture should be placed in a stable position with the hip in a little valgus before scrubbing.
- Obtain clear x-rays in both planes to allow accurate placement of guide wire and screw in the center of the head-neck fragment.
- Failure to position the screw in the center of the femoral head in both planes greatly increases the risk of screw cut-out and fixation failure.
- Short screws that do not reach 10 mm from the joint surface are also associated with a high risk of screw cut-out.
- Check the guide wire position regularly during drilling and screw insertion to ensure it is not being advanced into the pelvis.
- Use the reverse gear on the drill when removing threaded guide wires.
- Think about the need for rotational stability (additional parallel lag screw), and a trochanteric stabilization plate.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Authors   Malcolm Smith, Matthew Porteous

3.11.3   Extracapsular trochanteric femoral fractures (31-A2): stabilization with proximal femoral nail antirotation (PFNA)

Surgical management

- Stabilization with proximal femoral nail antirotation (PFNA)

Alternative implants

- Dynamic hip screw (DHS)
- Proximal femoral nail (PFN)

1   Introduction

- Extracapsular trochanteric and subtrochanteric fractures occur around the base of the femoral neck.
- They do not interrupt the blood circulation to the femoral head.
- The PFNA is designed for operative stabilization of "unstable" trochanteric fracture patterns, including 31-A2, 31-A3, and subtrochanteric fractures with unfavorable loading conditions (32-A, 32-B, 32-C).

Fig 3.11.3-1a–b
a   Preoperative x-ray: extracapsular proximal femoral fracture.
b   Postoperative x-ray: stabilization with PFNA.

- The PFNA is an intramedullary nail (available in short and long versions) that provides fixation of the head/neck fragment with a single helical blade and distal locking in the femur.
- There are nails of three different diameters.
- The short versions can be used for both sides, and the longer one which is curved to conform to the femoral shaft comes in a right and left version (for extended fracture zones).
- The PFNA is available with different neck/shaft angles (CCD angle). It is important therefore to measure the required angle preoperatively using an AP x-ray of the opposite intact femur as a guide. Measurement can either be done with a goniometer or by using a template. The PFNA with a CCD angle of 130º is used in most cases.
- Place the nail into the femoral canal first, insert the helical blade with the help of the aiming device, and distally lock the nail.
- The long PFNA must be locked distally freehand under x-ray control.
- The helical blade in the femoral neck allows for some impaction of the cancellous bone to facilitate healing.
- The helical blade compacts cancellous bone in the femoral head during insertion. The blade does not remove bone like a DHS or PFN screw. It provides greater control of rotation of the fracture than the proximal femoral nail (PFN).
- The PFNA usually allows for immediate weight bearing, which is important in the elderly.
- Good results can be achieved. Proper implant application and accurate reduction before stabilization are crucial.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used (conventional PFNA or long PFNA right/left)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- PFNA set
- Long PFNA implant selection (depending on fracture pattern)
- General orthopaedic instruments

- Radiolucent drive for distal locking of long PFNA
- Flexible reamers (eg, Synream) may be needed if using long PFNA

Equipment:
- Fracture table with extensions or radiolucent table
- Positioning accessories
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- With the patient anesthetized, reconfigure the table as, or transfer the patient to, a fracture table.
- Mount a padded perineal post on the injured side and fit side supports.
- Apply straight traction to the injured leg.
- Abduct and flex the opposite leg and place it out of the way in a gynecological leg holder (Fig 3.11.3-2a). Hip flexion usually allows greater abduction and the use of this support allows good access for the image intensifier. Alternatively, place the opposite leg in a padded boot and abduct it (Fig 3.11.3-2b). Lock all table joints.
- Fix or place the padded ipsilateral arm across the chest so it is out of the way.
- Exercise great care with soft tissues and skin pressure points, particularly in the elderly.

- Adjust the operating table to an appropriate height.
- Place the image intensifier obliquely between the spread legs and maneuver the C-arm over the injured hip for an AP view (Fig 3.11.3-3a).
- Swivel the C-arm approximately 90° for a lateral (axial) view (Fig 3.11.3-3b).
- Ensure that the image intensifier can obtain AP and lateral (axial) views of the hip by simple rotation of the C-arm.
- Unlock the table joints, reduce the fracture (usually by traction, adduction, internal rotation), and then lock all table joints.
- The surgeon must be satisfied with the reduction before the patient is prepared for surgery.
- If using a long PFNA, remember that the position of the image intensifier will have to be modified to get a lateral (axial) view for the distal locking of the nail.

Authors   Malcolm Smith, Matthew Porteous
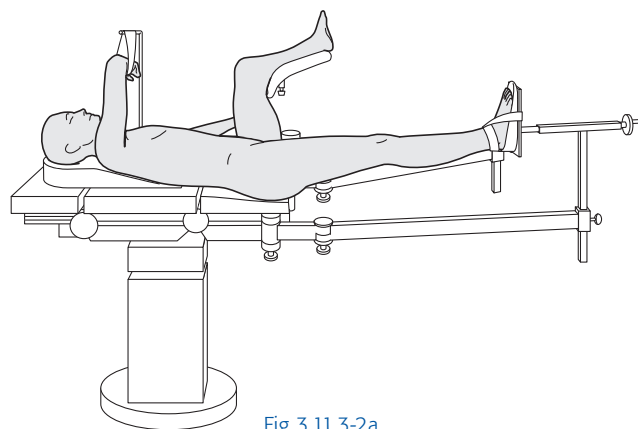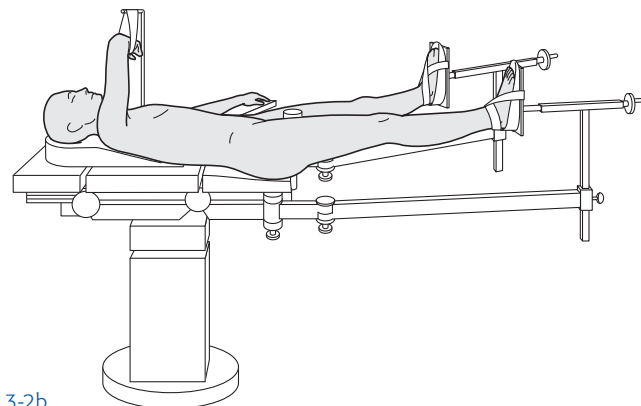
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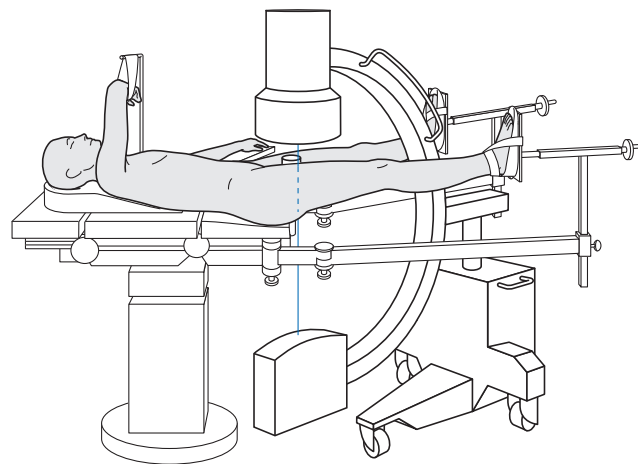
Fig 3.11.3-2b

Fig 3.11.3-3a
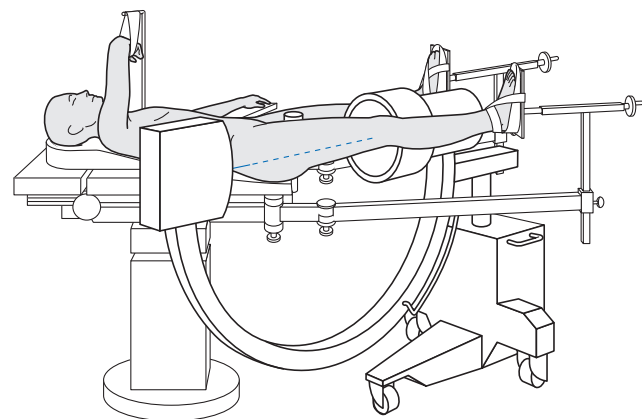
Fig 3.11.3-3b

5 Skin disinfecting and draping

- After positioning the patient, disinfect the exposed area with the appropriate antiseptic (Fig 3.11.3-4a).
- A single-use exclusion drape (curtain) may be used (Fig 3.11.3-4b).
- The image intensifier remains on the nonsterile side of the drape. Sterility must be maintained particularly when taking lateral (axial) x-rays.

- If traditional drapes are used, ensure a waterproof environment for the operative site.
- Drape the image intensifier.
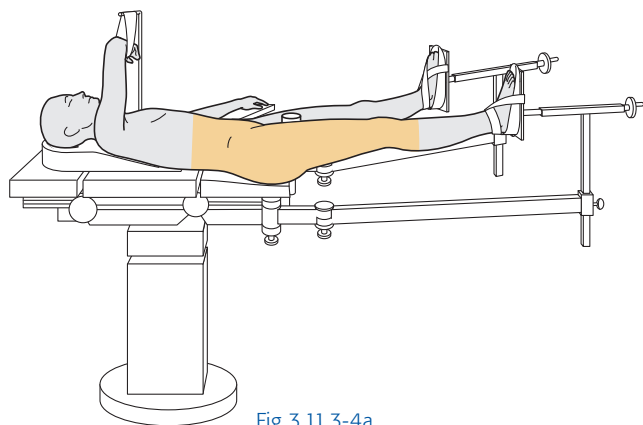
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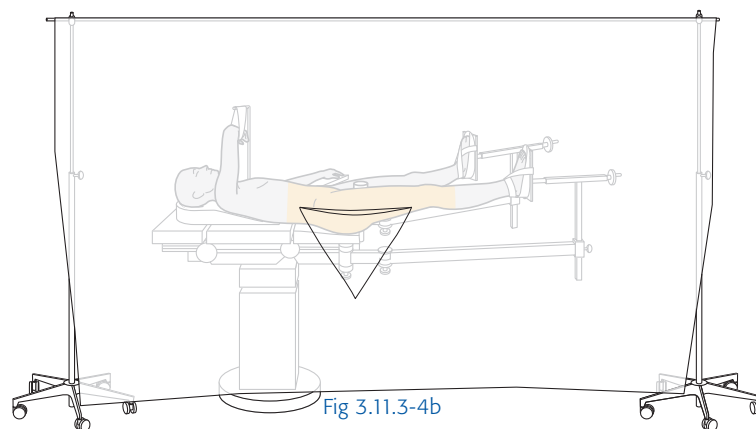
Fig 3.11.3-4b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- Place the image intensifier on the opposite side of the injury between the patient's legs.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.11.3-5).

Fig 3.11.3-5

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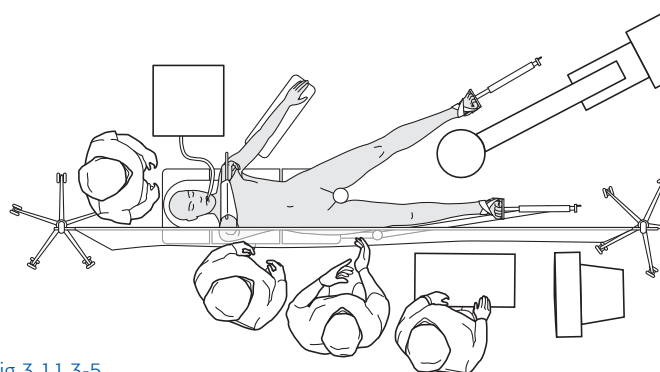
7   Instrumentation

Fig 3.11.3-6a   Implants
1.   PFNA nail
2.   PFNA blade
3.   Locking bolt 4.9 mm
4.   End cap
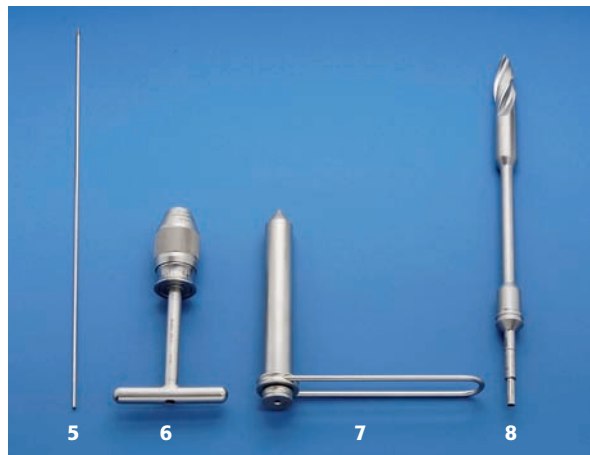
Fig 3.11.3-6b   Instruments for opening the lateral cortex
5.   Threaded guide wire 3.2 mm
6.   Universal chuck with T-handle
7.   Protection sleeve (two parts)
8.   Cannulated drill bit 17 mm
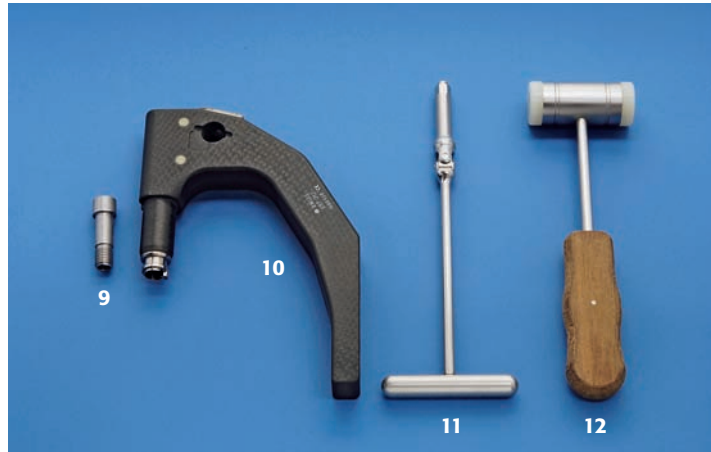
Fig 3.11.3-6c   Instruments for assembling the nail
9.   Connecting screw
10.   Insertion handle
11.   Socket wrench with T-handle
12.   Hammer
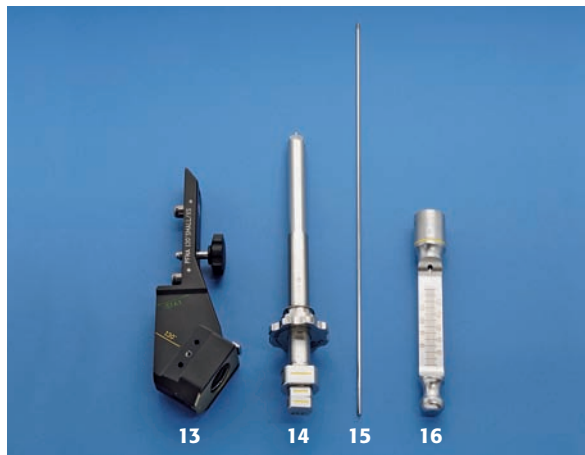
Fig 3.11.3-6d   Instruments for PFNA blade insertion
13.   Aiming arm for PFNA blade (select angle)
14.   Protection sleeve assembly (four parts)
15.   Threaded guide wire 3.2 mm
16.   Measuring device

Authors   Malcolm Smith, Matthew Porteous

Fig 3.11.3-6e   Instruments for PFNA blade insertion
17.   Cannulated drill bit 11 mm with stop
18.   Cannulated calibrated reamer 11 mm with fixation sleeve
19.   Inserter for PFNA blade
20.   Hammer

Fig 3.11.3-6f   Instruments for locking bolt insertion
21.   Drill sleeve assembly (three parts)
22.   Calibrated drill bit 4.0 mm
23.   Hexagonal screwdriver, long

8 Procedure and technique—step-by-step

- Determine the required nail diameter using the radiographic ruler under image intensification.
- Mark the femoral axes on the skin in both planes using the ruler.
- Incision: make a longitudinal incision about 5 cm long on the lateral aspect of the thigh ending just proximal to the tip of the greater trochanter.
- Insert a 3.2 mm guide wire through the tip of the greater trochanter into the femoral canal under AP and lateral (axial) x-ray control. In the lateral view the entry point should be in line with the central axis of the femoral neck.
- Accurate placement of this guide wire in both planes is very important. The wire should be at 6° from the long axis of the medullary cavity of the femur in the AP x-ray view. In the lateral view the wire has to be straight and in the axis of the medullary cavity of the femur.
- Place the soft-tissue protection sleeve over the guide wire.
- Open the medullary cavity with the cannulated 17.0 mm drill bit drilling down to its stop (Fig 3.11.3-7a).

- Assemble the PFNA onto the insertion handle (Fig 3.11.3-7b).
- Insert the nail into the proximal femur and gently advance it across the fracture site by hand until the proximal end of the nail reaches the tip of the greater trochanter.
- Check the position of the nail and fracture reduction with the image intensifier. A K-wire held over the center of the hole in the nail for the helical blade at the correct CCD angle should lie over the center of the femoral head on an AP x-ray image.
- Select and mount the desired aiming arm onto the insertion handle.
- Assess the anteversion of the neck by placing a K-wire along its anterior surface or by using the plane of the C-arm of the image intensifier when taking a true lateral view of the proximal femur.
- Insert the entire threaded targeting sleeve (three parts) into the side arm and click it into place. Incise the skin and advance the sleeve to the lateral cortex of the femur by turning the buttress nut (Fig 3.11.3-7c).
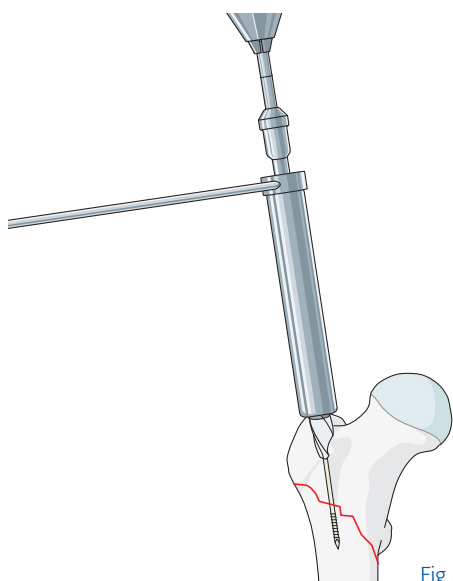
Fig 3.11.3-7a

Fig 3.11.3-7b

Fig 3.11.3-7c

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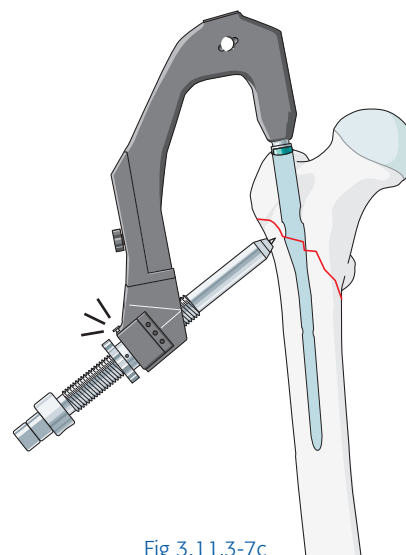
- Remove the trocar and replace it with a 3.2 mm threaded tip guide wire.
- Advance the guide wire into the center of the femoral head and check the position in both planes with the image intensifier. If the guide wire is not in the center, adjust the position of the nail and reinsert the guide wire until it is central in the femoral head.
- Determine the length for the blade using the direct measuring device (Fig 3.11.3-7d). The tip of the blade should lie approximately 10–15 mm from the joint surface. If the guide wire has been inserted 5 mm from the joint surface, subtract 10 mm from the measured length to determine the length of the required helical blade.

- Broach the lateral cortex with the 11 mm drill with stop.
- Set the fixation sleeve on the 11 mm reamer to the measured length of the helical blade and ream to the correct depth. Reaming is not required in patients with severe osteoporosis.
- Check that the guide wire does not bind and advance into the pelvis when using the tapered reamer.
- Assemble the appropriate length helical blade onto the inserter. The helical blade is supplied locked. To unlock it turn the inserter anticlockwise until it stops. In this position the blade can spin freely in its barrel.
- Place it over the guide wire and insert it with gentle hammer blows. Check that the tip of the blade ends in the center of the femoral head 10 mm from the articular surface of the hip.
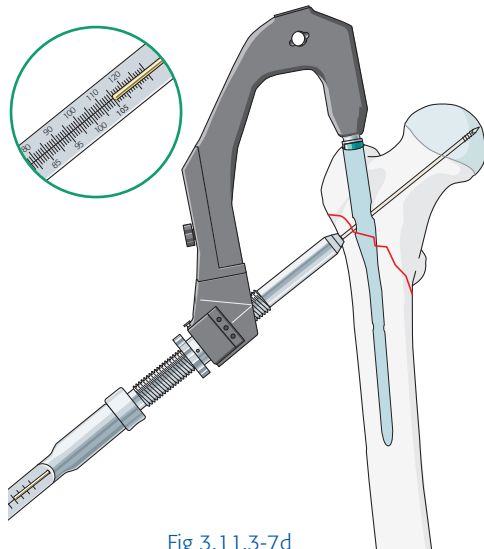
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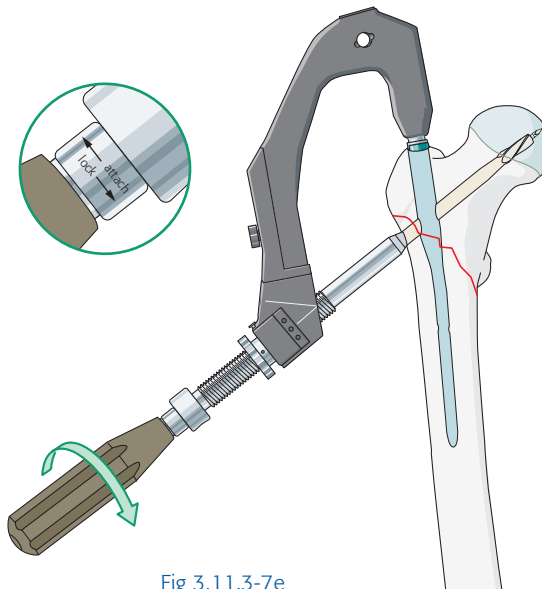
Fig 3.11.3-7e

- When fully inserted, lock the blade by rotating the handle of the inserter clockwise (Fig 3.11.3-7e) and then remove the insertion handle, targeting sleeve, and guide wire.
- Distal locking can be static (using the same aiming arm as for inserting the PFNA blade) (Fig 3.11.3-7f) or dynamic (using a separate aiming arm, marked dynamic).
- Pass the triple guide sleeve through the hole in the aiming arm and make a stab incision in the skin. Push the sleeve against the bone. Remove the trocar and replace it with a calibrated 4.0 mm drill. Drill the locking hole and read the bolt length off the calibrated drill bit. Remove the drill bit and inner sleeve and insert an appropriate length 4.9 mm locking bolt through the outer sleeve.

- If using the long PFNA, distal locking is performed freehand or with the radiolucent drive under lateral x-ray control. (This is described in the femoral nail technique, chapter 3.12.1).
- Remove the insertion handle from the nail.
- Insert the selected end cap. Use a guide wire with hook, the cannulated screwdriver shaft, and wrench (Fig 3.11.3-7g).
- Take and save copies of final x-rays in both planes.
- Close the wounds.

Further information is available on AO Teaching video 00125: Femur Trochanteric Fractures Intramedullary Nailing With the PFNA.

Fig 3.11.3-7f

Fig 3.11.3-7g

Authors   Malcolm Smith, Matthew Porteous

9   Specific perioperative care

- Be careful with the pressure areas, especially in the elderly.
- Confirm that the patient is secured on the fracture table and that the fracture is reduced.
- Maintain sterility as the image intensifier is rotated around the surgical field.

- Check that the guide wire is not advanced into the pelvis during drilling and screw insertion.
- Make sure that sharp instruments do not penetrate the plastic exclusion drape.

10   Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the implant unless hard copies have been taken from the image intensifier.
- The fixation should allow safe general lifting and handling of the patient for nursing.

- Most patients will be allowed to fully bear weight immediately.
- In the elderly, rehabilitation is often limited by other medical problems.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Make sure that new 3.2 mm guide wires are used each time, as damaged wires may bind to the cannulated drill bits or blade during insertion and can be accidentally advanced into the pelvis.
- Always have additional correct guide wires available.
- Confirm with the surgeon which angled-aiming arm to use.

- Confirm the agreed measurement for reamer setting and helical blade length with the surgeon.
- Check that the helical blade can spin freely in the barrel before insertion.
- At the end of the procedure check that the guide wire is not jammed in the drill.
- Flush and preclean (stylet, brush) all cannulated instruments carefully.
- Discard the guide wires after use.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Good patient set-up and fracture reduction are essential: the fracture should be placed in a stable position with the hip in a little valgus (traction).
- Check the guide wire entry point and position in both planes with the image intensifier before reaming the femur.
- Accurate guide wire placement is very important.
- Insert the PFNA nail by hand; avoid hammer blows as they may fracture the femur.

- The depth of nail insertion and its rotation will determine the correct position of the blade in the neck.
- Make sure that the helical blade is free to spin during insertion and is correctly locked after insertion.
- Regularly check the guide wire position during drilling and blade insertion.
- Use the reverse gear when removing threaded guide wires.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Authors   Malcolm Smith, Matthew Porteous

3.11.4   Subtrochanteric femoral fractures (32-A2): stabilization with proximal femoral nail (PFN)

Surgical management

- Stabilization with proximal femoral nail (PFN)

Alternative implants

- Proximal femoral nail antirotation (PFNA)
- Trochanteric fixation nail (TFN)
- 95° angled blade plate
- Proximal femoral locking plate

1   Introduction

- Subtrochanteric fractures share many biomechanical features with proximal femur fractures. They are often pathological.
- In displaced fractures the proximal fragment is usually flexed and abducted, making reduction difficult.
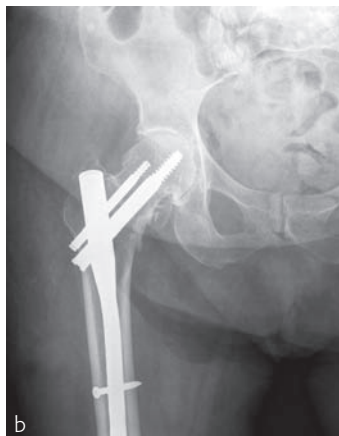
Fig 3.11.4-1a–b
a   Preoperative x-ray: subtrochanteric femoral fracture.
b   Postoperative x-ray: stabilization with proximal femoral nail (PFN).

- Displaced fractures are difficult to reduce and stabilize; consequently, malunion, nonunion, and implant cut-out are not infrequent complications of treatment.
- Several fixation devices can be used. Intramedullary nails that provide an antegrade locking option into the femoral neck are advantageous. The DHS and DCS are not indicated.
- The PFN is a short intramedullary nail that provides fixation of the head/neck fragment with two parallel antegrade screws and distal locking in the femur.
- There are three different diameters of PFN available. In a short version the implants are not sided. In a long version they are sided right and left because of their curved profile (for extended fracture zones).
- Place the nail into the femoral canal first, then insert the screws with the help of the aiming device, and finally distally lock the nail.
- The long PFN must be locked distally freehand or using a radiolucent drive under x-ray control.
- The PFN nails allow for immediate weight bearing, which is imperative in the elderly.
- Problems may occur if the fracture is badly reduced, or if the implant is badly placed.
- Patients' comorbidities are significant factors for a general prognosis.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used (standard or long version right/left)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- PFN set
- Long PFN implant selection (depending on fracture pattern)
- General orthopaedic instruments

- Compatible air or battery drill with attachments
- Radiolucent drive for distal locking of long PFN
- Flexible reamers (eg, Synream, may be needed if using a long PFN)

Equipment:
- Fracture table with extensions or radiolucent table
- Positioning accessories
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- When the patient is anesthetized, reconfigure the table as a fracture table.
- Mount a padded perineal post to the injured side and fit side supports.
- Apply straight traction to the injured leg.
- Place the opposite leg in a padded boot and abduct it (Fig 3.11.4-2a) (hip flexion may permit more abduction, or place it out of the way in a gynecological leg holder) (Fig 3.11.4-2b) to allow access for the image intensifier. Lock all table joints.
- Fix or hang the padded ipsilateral arm across the chest so it is out of the way.
- Exercise great care with soft tissues and skin pressure points, particularly in the elderly.
- Adjust the operating table to an appropriate height.
- Place the image intensifier obliquely between the spread legs over the injured hip for an AP view (Fig 3.11.4-3a).

- Rotate the C-arm through 90° for lateral (axial) view (Fig 3.11.4-3b).
- Ensure that the image intensifier can obtain AP and lateral (axial) views of the hip by simple rotation of the C-arm.
- Unlock the table joints, reduce the fracture (usually by traction, adduction, internal rotation), and then lock all table joints again.
- The surgeon has to be satisfied with the reduction before the patient is prepared for surgery.
- If a flat radiolucent table is used, the patient is placed supine. The injured leg can be held in a frog position to allow the best x-ray view of the femoral head.
- If using a long PFN , the position of the image intensifier needs to be modified to get a lateral (axial) view of the distal locking of the nail.

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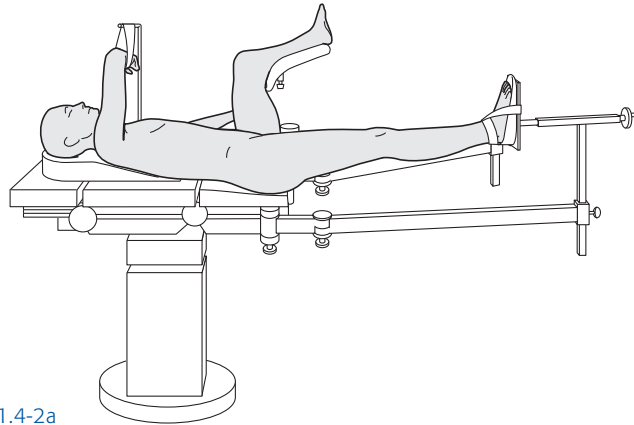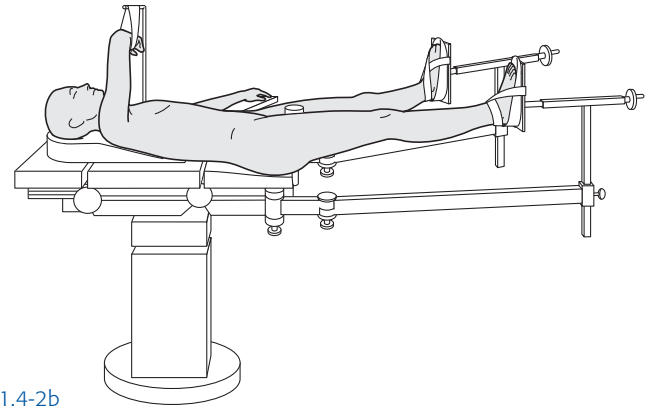
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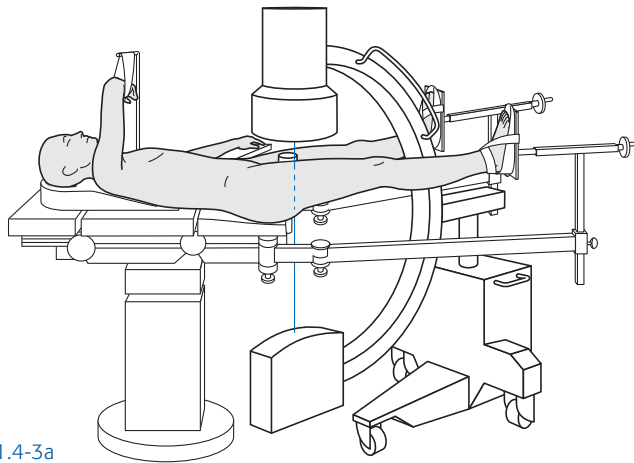
Fig 3.11.4-2b

Fig 3.11.4-3a
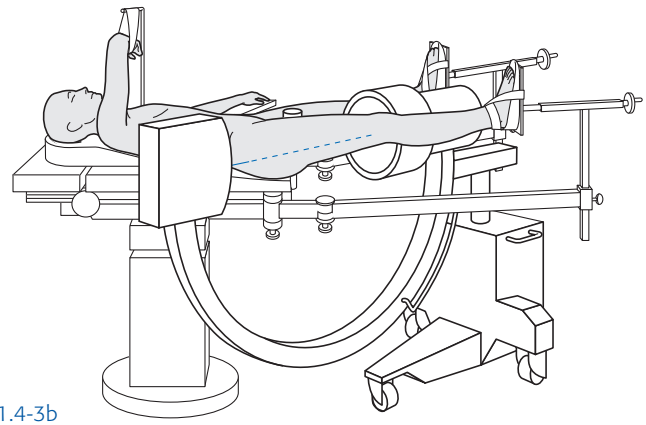
Fig 3.11.4-3b

5 Skin disinfecting and draping

- After positioning the patient, disinfect the exposed area with the appropriate antiseptic (Fig 3.11.4-4a).
- A single-use exclusion drape (curtain) may be used (Fig 3.11.4-4b).
- The image intensifier remains on the nonsterile side of the drape. Sterility must be maintained particularly when taking lateral (axial) x-rays.

- The whole femur needs to be draped (distal locking).
- If traditional drapes are used, ensure a waterproof environment for the operative site.
- Drape the image intensifier.
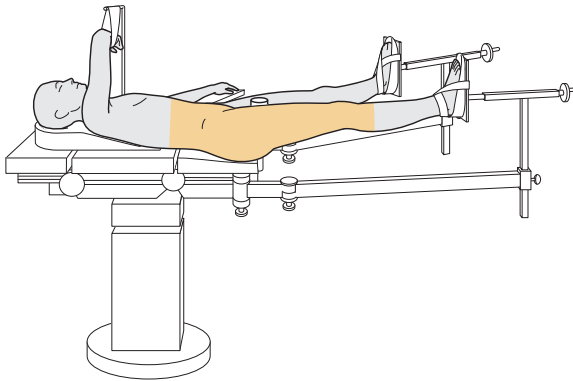
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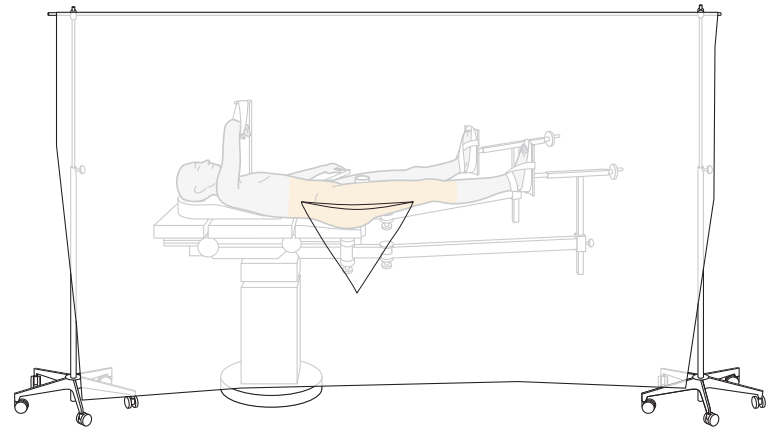
Fig 3.11.4-4b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- Place the image intensifier on the opposite side to the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.11.4-5).

Fig 3.11.4-5

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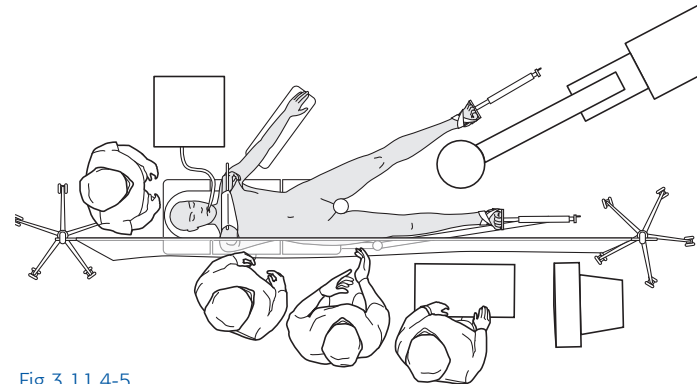
7   Instrumentation

Fig 3.11.4-6a   Implants
1.   End cap
2.   PFN nail
3.   Femoral neck screw 11 mm, self-tapping
4.   Hip pin 6.5 mm, self-tapping
5.   Locking bolt 4.9 mm
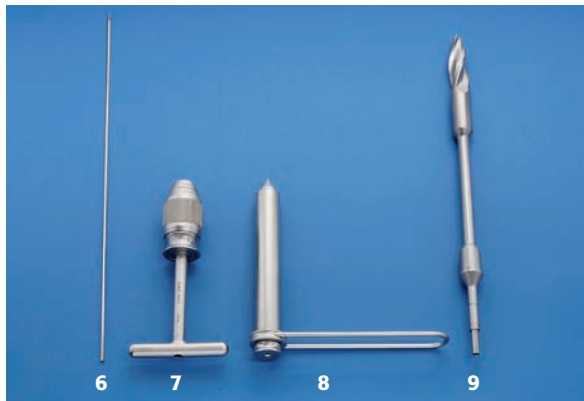
Fig 3.11.4-6b   Instruments for opening the lateral cortex
6.   Threaded guide wire 2.8 mm
7.   Universal chuck with T-handle
8.   Protection sleeve (two parts)
9.   Cannulated drill bit 17 mm

Fig 3.11.4-6c   Instruments for assembling the nail
10.   Connecting screw
11.   Insertion handle
12.   Socket wrench with T-handle
13.   Hammer

Fig 3.11.4-6d   Instruments for insertion of the femoral neck screw
14. Aiming arm (select angle)
15. Protection sleeve assembly (pink, three parts)
16. Threaded guide wire 2.8 mm
17. Direct measuring device
18. Cannulated reamer 11 mm with fixation sleeve
19. Wrench with coupling screw and compression nut
20. Pin wrench

Fig 3.11.4-6e   Instruments for insertion of hip pin
21. Guide wire 2.8 mm
22. Cannulated drill bit 6.5 mm
23. Drill sleeve assembly for hip pin (blue, three parts)
24. Cannulated screwdriver for PFN

Fig 3.11.4-6f   Instruments for insertion of locking bolts
25. Drill bit 4.0 mm
26. Drill sleeve assembly (green, three parts)
27. Depth gauge
28. Hexagonal screwdriver

Authors   Malcolm Smith, Matthew Porteous

Fig 3.11.4-6g   Instruments for removal of PFN
29.   Cannulated screwdriver for hip pin
30.   Hexagonal screwdriver for locking bolts
31.   Wrench for femoral neck screw with coupling screw
32.   Wrench with T-handle
33.   Extraction guide rod
34.   Pin wrench
35.   Slide hammer

8 Procedure and technique—step-by-step

- Determine the required nail diameter using the radiographic ruler under the guidance of the image intensifier.
- Mark the femoral axes on the skin in both planes using the ruler.
- Incision: make a longitudinal incision on the lateral aspect of the thigh, 5 cm above the tip of the greater trochanter.
- Insert a 2.8 mm guide wire through the tip of the greater trochanter into the femoral canal under AP and lateral (axial) x-ray control (Fig 3.11.4-7a).
- Accurate placement of this wire in both planes is essential.
- Place the drill sleeve assembly over the guide wire.
- Open the medullary cavity with the cannulated 17.0 mm drill bit, drilling down to its stop (Fig 3.11.4-7b).

- Assemble the PFN onto the insertion handle (Fig 3.11.4-7c) and gently advance it by hand into the proximal femur and across the fracture until its proximal end is at the level of the tip of the trochanter. Check the position in both planes with the image intensifier.
- Mount the aiming arm onto the insertion handle.
- Assess the anteversion of the neck by placing a K-wire along its anterior surface (blunt end first), or by using the plane of the C-arm of the image intensifier when taking a true lateral view of the femoral neck.
- Place the larger (pink) drill sleeve assembly through the aiming arm. Make a stab incision in the skin and push it against the bone.
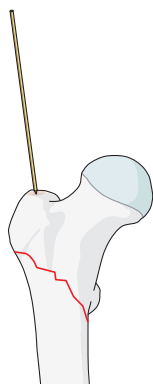
Fig 3.11.4-7a

Fig 3.11.4-7b

Fig 3.11.4-7c

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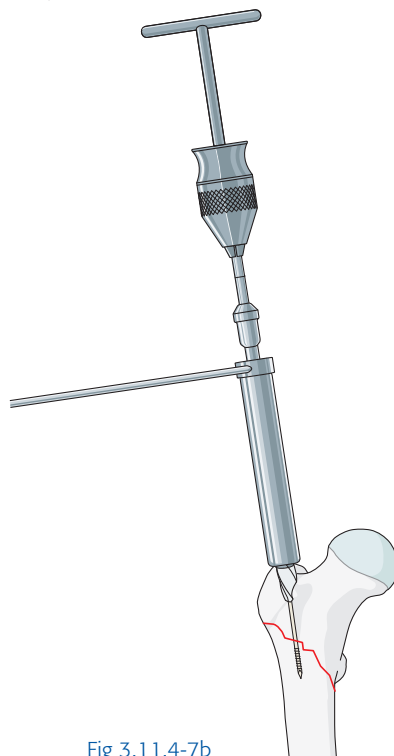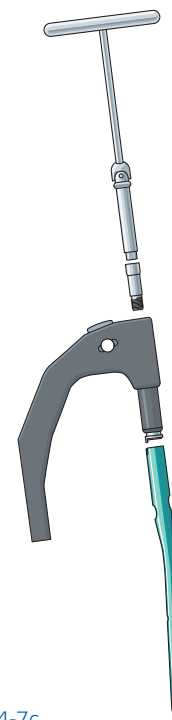
- Remove the trocar and insert the first 2.8 mm guide wire through the protection sleeve into the femoral head under x-ray control. It should lie in the distal part of the head on the AP view and centrally on the lateral view.
- Correct the wire position if necessary by adjusting the position of the nail and reinserting the guide wire.
- Insert the blue-coated protection sleeve assembly proximal to the pink one, and place the second 2.8 mm guide wire for the smaller hip pin into the femoral head (Fig 3.11.4-7d).
- The wire for the femoral neck screw should be 1 cm short of the articular surface, the wire for the hip pin should be 2 cm shorter so the tips of the wires are horizontally in line.
- The guide wires determine the final position of both screws.
- Measure the length for both screws with the direct measuring gauge (Fig 3.11.4-7e).

- Drill the hole for the (blue) hip pin with the 6.5 mm drill bit to its stop and insert the hip pin with the cannulated screwdriver (tapping only in dense bone).
- Set the 11.0 mm reamer to the correct length for the femoral neck screw. To do this read from the top of the drill bit to the number above the fixation sleeve. Perform the reaming (Fig 3.11.4-7f).
- Assemble the inserter for the (pink) femoral neck screw and secure it tightly to the selected screw. Insert it over the guide wire through the outer sleeve (Fig 3.11.4-7g).
- Remove the guide wires using the drill in reverse gear.
- Perform static and/or dynamic distal locking using the appropriate hole of the aiming arm.
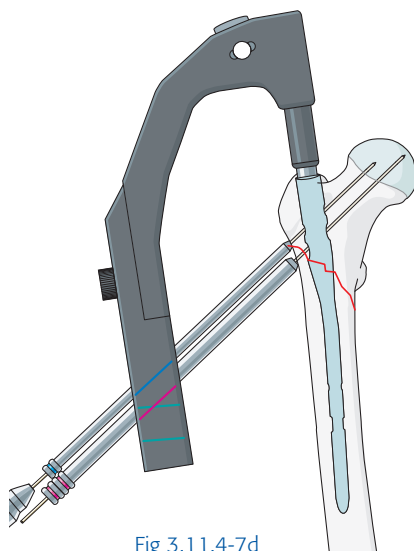
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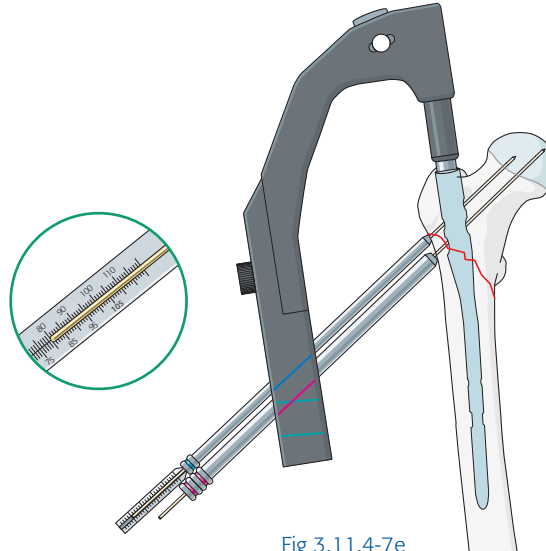
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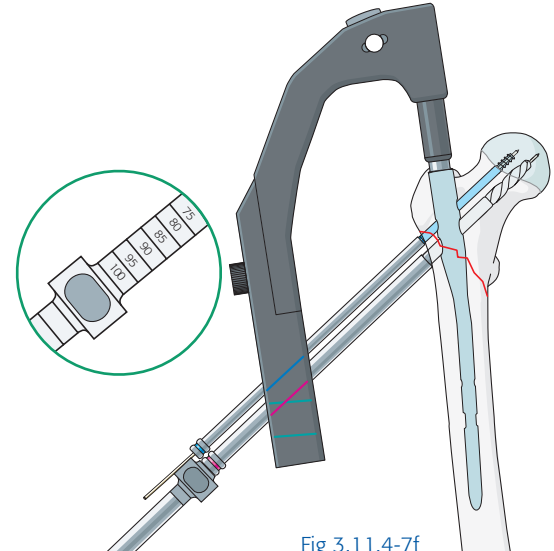
Fig 3.11.4-7f

- Pass the green drill sleeve assembly through the aiming arm hole and make a stab incision in the skin to rest against the bone. Remove the trocar and make a drill hole with the 4.0 mm calibrated drill bit. Read off the screw length from the drill calibration (Fig 3.11.4-7h).
- Remove the drill sleeve and insert a 4.9 mm locking bolt of appropriate length through the outer sleeve. The screw tip should penetrate the far cortex of the bone (Fig 11.4-7i).
- If using a long PFN, distal locking is performed freehand or with a radiolucent drive under x-ray control (see distal locking section in chapter 3.12.1 on the femoral nail).
- An end cap may be inserted after removal of the insertion handle.
- Take and save copies of final x-rays in both planes.
- Close the wounds.

Further information is available on AO Teaching video 20173: The Proximal Femoral Nail.
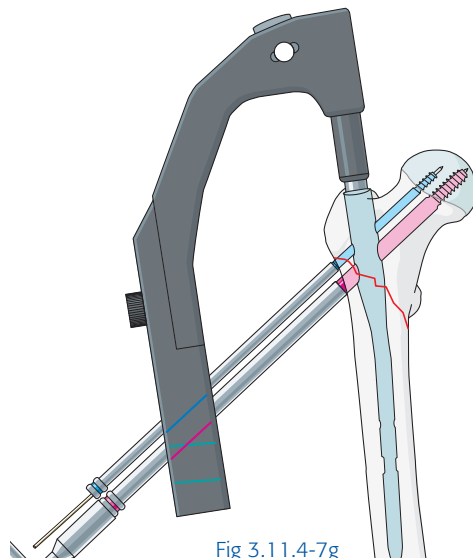
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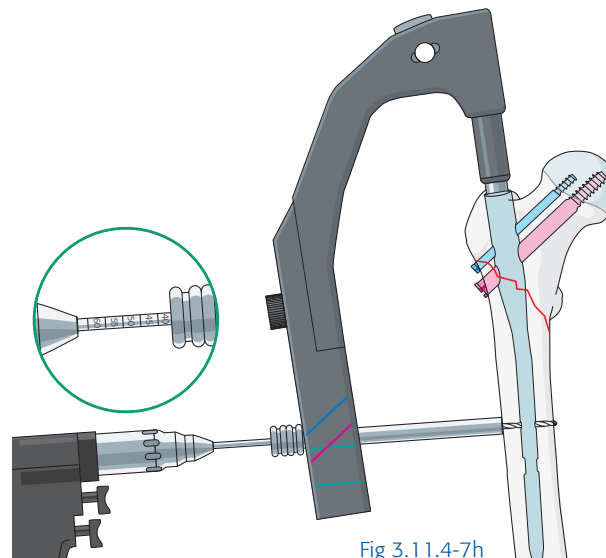
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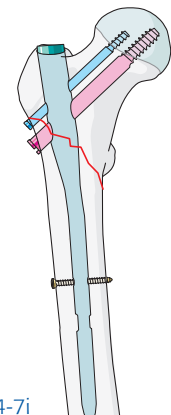
Fig 3.11.4-7i

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9   Specific perioperative care

- Be careful with the pressure areas, especially in the elderly.
- Check the patient's stability on the fracture table and the fracture reduction.
- Maintain sterility as the image intensifier is rotated around the surgical field.
- Check the guide wire position during drilling and screw insertion.
- Make sure that sharp instruments do not penetrate the plastic exclusion drape.

10   Specific postoperative care

- The fixation should allow safe general lifting and handling of the patient for nursing.
- The day after surgery, formal x-rays are taken for documentation of the fracture, reduction, and implant position.
- Immediate weight bearing is generally allowed.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Mount the aiming arm onto the insertion handle after insertion of the nail.
- Make sure that new 2.8 mm guide wires are used each time, as damaged wires may bind to the drill or screw during insertion and can be accidentally advanced into the pelvis.
- Always have additional correct guide wires available.
- Set the reamer correctly for the femoral neck screw.
- Do not confuse the measurements of the two screws.
- At the end of the procedure check that the guide wire is not jammed in the drill.
- Flush and preclean (stylet, brush) all cannulated instruments carefully.
- Discard the guide wires after use.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Good patient set-up and fracture reduction is essential: the fracture should be placed in a stable position with the hip in a little valgus.
- It is better to perform an open reduction of the fracture than to insert the nail closed with the fracture poorly reduced. Malreduction leads to a high nonunion rate as well as a high incidence of implant failure.
- Correct guide wire placement in both planes is vital. Failing to get this right makes the rest of the operation very difficult and can lead to femoral fracture.
- Insert the PFN by hand, do not use a hammer or you may fracture the femur.
- The position of the screws in the femoral neck is determined by the depth of nail insertion and its rotation.
- Insert the guide wire for the femoral neck screw first, followed by the second wire for the hip pin.
- Drill and insert the hip pin first, then drill and insert the femoral neck screw.
- Regularly check the guide wire positions with the image intensifier during drilling and screw insertion to ensure that they do not jam and advance into the pelvis.
- Use the reverse gear when removing threaded guide wires.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Authors   Malcolm Smith, Matthew Porteous

3.11.5   Special subtrochanteric femoral fractures (32-B2): stabilization with 95° condylar blade plate

Surgical management

- 95° condylar blade plate (angled blade plate)

Alternative implant

- Proximal femoral locking plate

1   Introduction

Fig 3.11.5-1a–b
a   Preoperative x-ray: wedge fracture of proximal femoral shaft.
b   Postoperative x-ray: stabilization with reverse 95° condylar blade plate.

- The 95° angled blade plate may be used to stabilize proximal femoral fractures.
- It is particularly useful when there is previous deformity, malunion, or nonunion.
- Correction of a varus deformity is often required.
- The angled blade plate is a single piece–fixed angle device with a U-shaped blade and side plate secured with 4.5 mm cortex screws.
- There are a variety of blade and plate lengths available.
- A seating chisel is used to prepare the exact placement of the blade in the femoral neck.
- The blade is difficult to insert as it has to be correctly orientated in three planes. Precise preoperative planning is always required.
- The success of the surgery depends on the position of the implant and the degree of stability achieved.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies
- Bone grafting planned

Instrumentation required:
- Angled blade plate instrument set
- Angled blade plate 95° implant selection
- Basic screw and instrument set 4.5 mm
- General orthopaedic instruments

- Compatible air or battery drill with attachments
- Saw (for osteotomy if required)
- Bone grafting instrument set

Equipment:
- Fracture table with extensions or radiolucent table
- Positioning accessories
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- With the patient anesthetized, reconfigure the table as, or transfer the patient to, a fracture table.
- Mount a perineal post on the injured side and fit side supports.
- Apply straight traction to the injured leg.
- Abduct and flex the opposite leg and place it out of the way in a gynecological leg holder (Fig 3.11.5-2a). Hip flexion usually allows greater abduction and the use of this support allows good access for the image intensifier. Alternatively, place the opposite leg in a padded boot and abduct it (Fig 3.11.5-2b). Lock all table joints.
- Fix or place the padded ipsilateral arm across the chest so it is out of the way.

- Take great care with the soft tissues and skin pressure points, particularly in the elderly.
- Adjust the operating table to an appropriate height.
- Place the image intensifier obliquely between the spread legs and maneuver the C-arm over the injured hip for an AP view (Fig 3.11.5-3a).
- Swivel the C-arm approximately 90° for a lateral (axial) view (Fig 3.11.5-3b).
- Ensure that the image intensifier can obtain AP and lateral views of the hip by simple rotation of the C-arm. Do not prepare and drape the patient until good-quality x-rays are obtainable.
- Unlock the table joints, reduce the fracture (usually by traction, adduction, internal rotation), and then lock all table joints.

Authors   Malcolm Smith, Matthew Porteous

- The surgeon must be satisfied with the position before the patient is prepared for surgery.
- A standard operating table may be used as an alternative.
- Place the patient supine on a standard table. This is the preferred position if undertaking a corrective intertrochanteric osteotomy.
- A sandbag may be inserted under the buttock on the operative side (Fig 3.11.5-4).
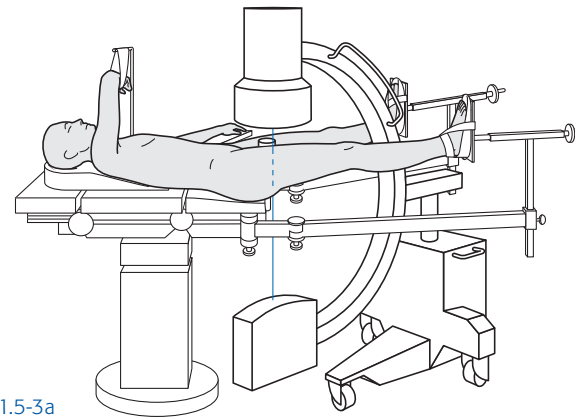
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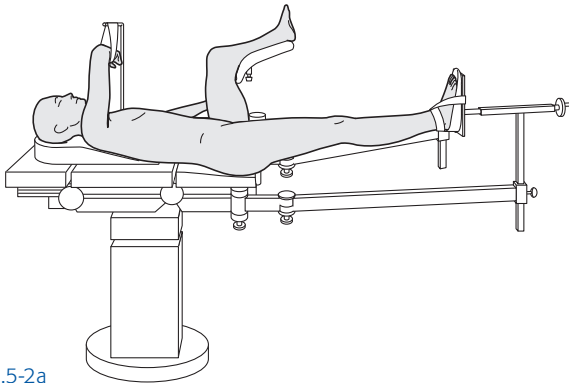
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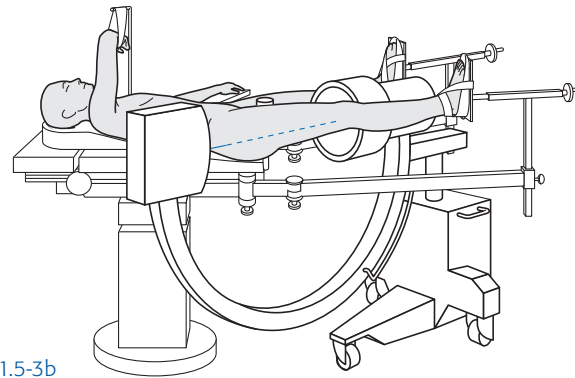
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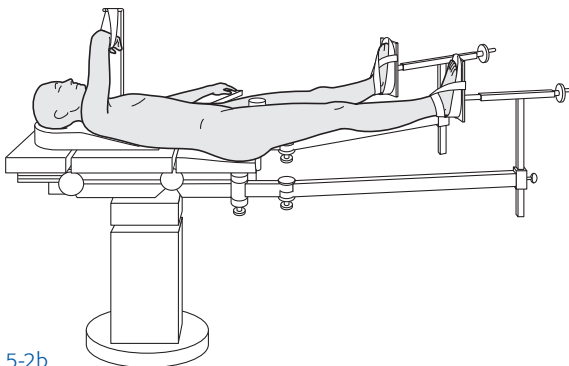
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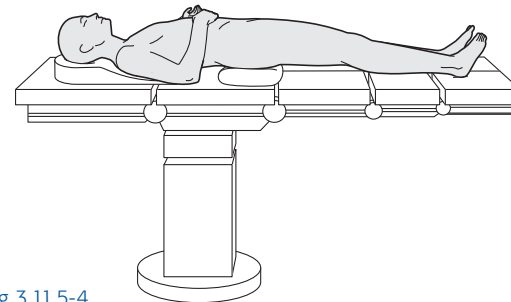
Fig 3.11.5-4

5   Skin disinfecting and draping

- After positioning the patient, disinfect the exposed area with the appropriate antiseptic (Fig 3.11.5-5a).
- A single-use exclusion drape (curtain) may be used (Fig 3.11.5-5b).
- The image intensifier remains on the nonsterile side of the drape. Sterility must be maintained while taking AP and lateral x-rays.

- If traditional drapes are used, ensure a waterproof environment for the operative site.
- Draping should always allow access for taking a bone graft (Fig 3.11.5-5c).
- Drape the image intensifier.
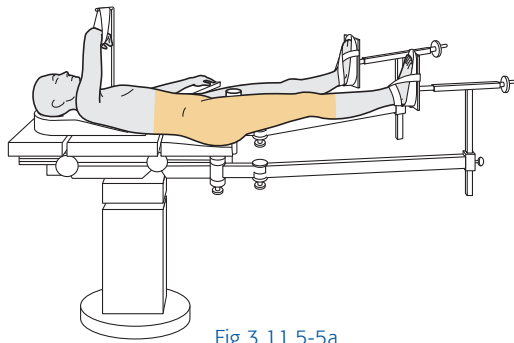
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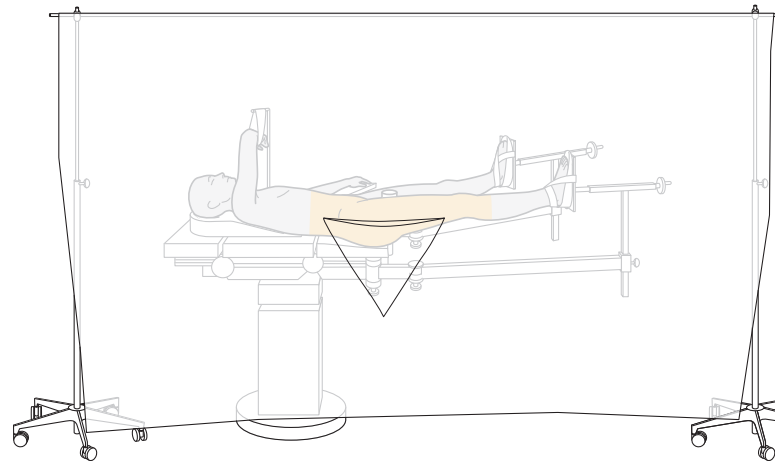
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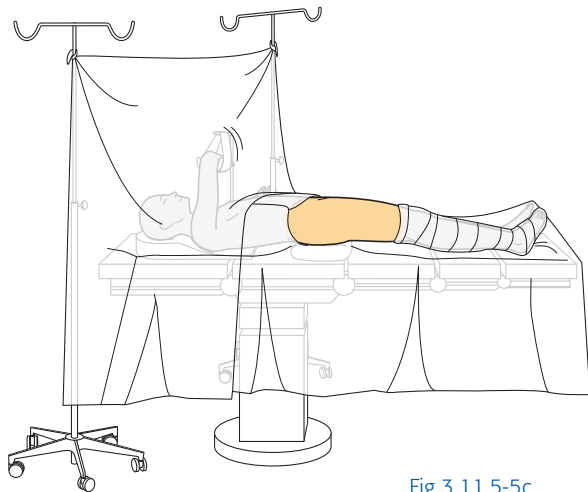
Fig 3.11.5-5c

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6   Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- Place the image intensifier on the opposite side to the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.11.5-6).
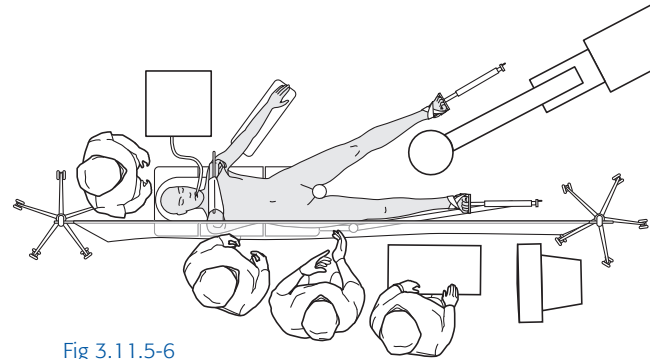
Fig 3.11.5-6

7   Instrumentation

Fig 3.11.5-7a   Implants
1   95° Condylar blade plate
2   Cancellous bone screw 6.5 mm
3   Cortex screw 4.5 mm

Fig 3.11.5-7b Instruments for opening lateral cortex
4.   Long K-wire, 2.0 mm
5.   Condylar plate guide
6.   Triple drill guide
7.   Drill bit 4.5 mm
8.   Router
9.   Chisel handle
10.   Chisel blade
11.   Hammer

Fig 3.11.5-7c Instruments for plate insertion
12.   Seating chisel
13.   Chisel guide (use screwdriver to adjust the angle of the guide)
14.   Slotted hammer
15.   Inserter
16.   Socket wrench
17.   Combination wrench 11 mm
18.   Impactor
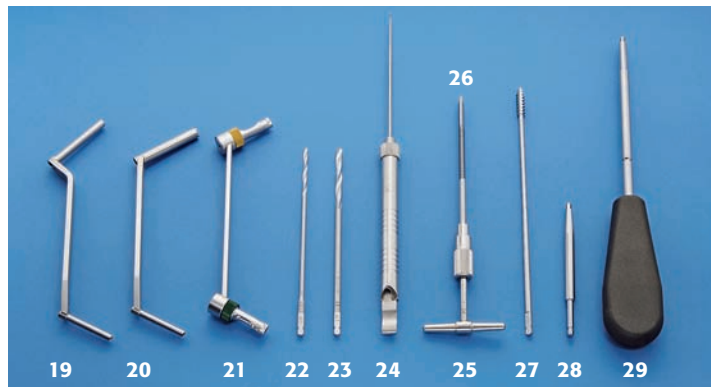
Fig 3.11.5-7d Instruments for plate fixation
19.   Double drill sleeve 4.5/3.2 mm
20.   Double drill sleeve 6.5/3.2 mm
21.   DCP drill sleeve 4.5 nn
22.   Drill bit 3.2 mm
23.   Drill bit 4.5 mm
24.   Depth gauge
25.   T-handle
26.   Tap for 4.5 mm cortex screw
27.   Tap for 6.5 mm cancellous bone screw
28.   Screwdriver shaft
29.   Hexagonal screwdriver

Authors   Malcolm Smith, Matthew Porteous

8   Procedure and technique—step-by-step

- Incision: make a longitudinal incision on the lateral aspect of the thigh. The length of the incision is determined by the size of the implant to be used.
- Identify the plane of the anteversion of the femoral neck with a 2.0 mm K-wire (inserted blunt end first).
- Using the preoperative plan, determine the exact entry point for the seating chisel, mark it, and confirm the position with the image intensifier (Fig 3.11.5-8a).
- Prepare a slot in the lateral cortex with a 16.0 mm chisel or three 4.5 mm drill holes placed with the triple guide and link them with the router to form a slot (Fig 3.11.5-8b–c).

- Attach the chisel guide onto the seating chisel. Set and fix the flap at the desired angle.
- With a slotted hammer—to control rotation—hammer the seating chisel, under x-ray control in both planes, into the femoral neck until the required depth is reached (Fig 3.11.5-8d).
- When inserting the chisel, take great care to check the degree of anteversion, rotation, and angle to the femoral shaft. Any inaccuracy will result in plate malpositioning.
- Determine the required blade length off the scale on the chisel.
- Mount the chosen blade plate correctly onto the inserter: the handle of the inserter and the blade of the plate must be
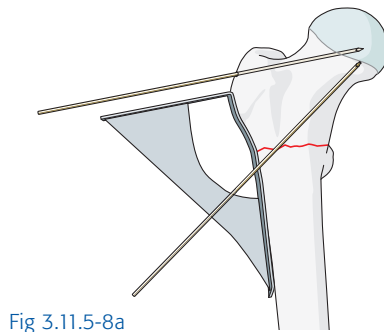
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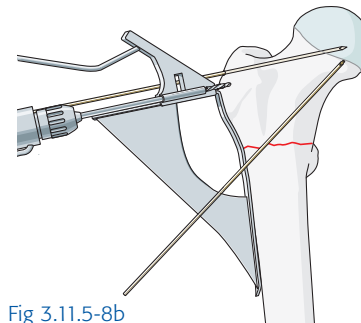
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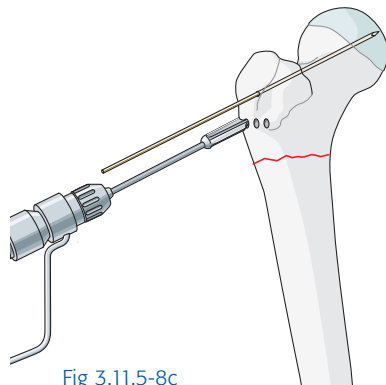
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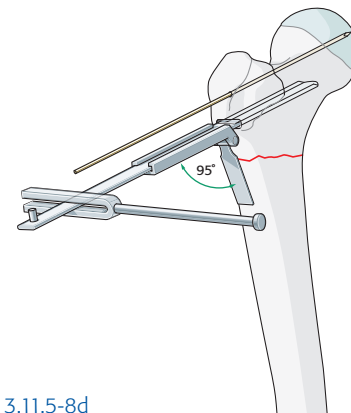
Fig 3.11.5-8d

aligned in the same plane (the notched head of the inserter allows for fine adjustment). Tighten the bolt of the insertion handle firmly.

- When the plate is ready to be inserted, remove the seating chisel.
- Insert the plate with gentle hammer blows (Fig 3.11.5-8e).
- Use the impactor to seat the final plate position.
- If required, insert 6.5 mm cancellous bone screws into the two round holes next to the blade (Fig 3.11.5-8f).
- Drill a 3.2 mm hole using the drill guide, measure the depth, and tap the outer cortex of the bone. Insert a fully threaded cancellous bone screw of appropriate length.
- Fix the plate with 4.5 mm cortex screws.
- If necessary, axial compression may be achieved with the insertion of a compression screw (or with the articulated tension device).

- Using the gold-colored drill guide inserted into a distal plate hole with the arrow pointing toward the fracture, drill an eccentric 3.2 mm hole. Measure the depth and tap the hole fully. Insert a 4.5 mm cortex screw of correct length and tightened it.
- The remaining distal screws are inserted in neutral mode using the green-colored drill guide. Measure the depth, tap the hole, and insert the cortex screw (Fig 3.11.5-8g).
- Take and save copies of final x-rays in both planes.
- Close the wound.

Further information is available on AO Teaching video 00064: Condylar Plate Fixation in the Distal Femur.
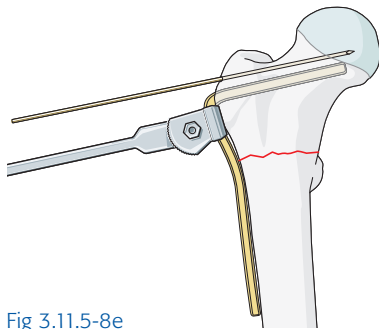
Fig 3.11.5-8e
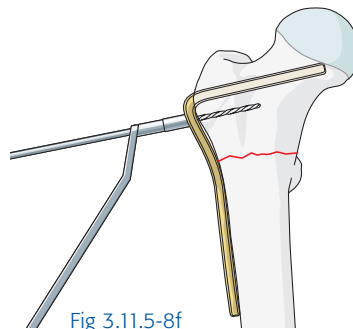
Fig 3.11.5-8f
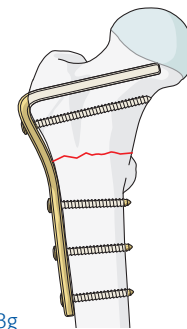
Fig 3.11.5-8g

Authors   Malcolm Smith, Matthew Porteous

9   Specific perioperative care

- Be careful with the pressure areas, especially in the elderly.
- Confirm that the patient is secured on the fracture table (or standard table) and that the fracture is reduced.
- Maintain sterility as the image intensifier is rotated around the surgical field.
- Make sure that sharp instruments do not penetrate the plastic exclusion drape.

10   Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the implant, unless hard copies have been taken from the image intensifier.
- The fixation should allow safe general lifting and handling of the patient for nursing.
- Mobilization of the patient depends on the stability obtained by the fixation.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Do not confuse seating chisels (different profiles) for adults, adolescents, and children.
- Mount the plate correctly on the inserter.
- Have the mounted plate ready for immediate use when the seating chisel is removed by the surgeon.
- Consider the need for bone graft set.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Precise preoperative planning is absolutely mandatory for the exact placement of the plate.
- Confirm the availability of the required implant before surgery.
- Always drape the patient to allow access for taking a bone graft.
- Ensure correct placement of the seating chisel in valgus/varus, anteversion/retroversion, and rotation as it is inserted into the femoral neck.
- If an osteotomy is required, the seating chisel is inserted and then loosened before the osteotomy is performed.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.12 Diaphyseal femoral fractures in adults and children

Author   Nigel D Rossiter

3.12   Diaphyseal femoral fractures in adults and children

Implants and surgical technique	Cases

Implants and surgical technique

- Cannulated femoral nail (CFN)
- Distal femoral nail (DFN)
- Titanium elastic nails (TENs)

Cases

- Diaphyseal adult femoral fracture (32-A3)
- Diaphyseal adult femoral fracture (32-C3)
- Diaphyseal children femoral fracture (32-A)

Introduction

- The Müller AO/OTA Classification divides femoral diaphyseal fractures in adults into three groups:
  - 32-A: simple—spiral, oblique, or transverse
  - 32-B: wedge—with some continuity between main fragments
  - 32-C: multifragmentary—no continuity between main fragments
- Femoral fractures make up 2.5% of all fractures. They mainly occur in three groups of patients:
  - Children, as a result of twisting injuries, high-energy direct trauma, or nonaccidental injury
  - High-energy trauma in young, often male, adults—injuries are usually associated with other injuries
  - Low-energy trauma in osteopenic bone—usually sustained by the patient in a low-energy fall
- Locked intramedullary nailing has revolutionized the management of diaphyseal fractures in adults.
- Nails may be inserted antegrade through the piriform fossa, the tip of or the lateral part of the greater trochanter depending on the nail design, or in a retrograde direction through the knee.
- While most adult femoral diaphyseal fractures are managed with locked nails, newer plates with locking head screws are gaining popularity in some osteoporotic fractures and are the treatment of choice in periprosthetic fractures.
- Plating of the adult femoral shaft with absolute stability has few indications in fresh diaphyseal fractures, but is still widely used in the management of nonunion and malunion.
- In the polytraumatized patient (ISS > 17), femoral fractures represent severe life-threatening injuries requiring urgent management and stabilization as early as possible. Patients who are physiologically stable may be managed with early total care and have immediate definitive fixation. In unstable patients a damage-control surgery strategy should be applied with stabilization of the long-bone fractures with external fixators followed by definitive internal fixation after a few days (see chapter 2.9).
- In children with open-growth plates intramedullary nailing with "adult-type nails" is not recommended because of the risk of irreversible damage caused to the growth plate by nail insertion leading to growth arrest.
- Flexible elastic nails have dramatically changed the management of femoral fractures in children and are the treatment of choice between 3 years and about 14 years.

Müller AO/OTA Classification—diaphyseal femur

| 32-A1 | 32-A2 | 32-A3 | 32-B1 | 32-B2 | 32-B3 | 32-C1 | 32-C2 | 32-C3 |

32-A   simple fracture
32-A1   spiral
32-A2   oblique ($\geq$ 30°)
32-A3   transverse (< 30°)
32-A(1−3).1 = subtrochanteric fracture

32-B   wedge fracture
32-B1   spiral wedge
32-B2   bending wedge
32-B3   fragmented wedge
32-B(1−3).1 = subtrochanteric fracture

32-C   complex fracture
32-C1   spiral
32-C2   segmental
32-C3   irregular
32-C(1−3).1 = subtrochanteric fracture

Author   Nigel D Rossiter

3.12.1   Diaphyseal adult femoral fracture (32-A3): stabilization with cannulated femoral nail (CFN)

Surgical management

- Closed (indirect) reduction and stabilization with cannulated femoral nail (CFN)

Alternative implants

- Solid (unreamed) femoral nail (UFN)
- Distal femoral nail (DFN)
- Expert retrograde/antegrade femoral nail (R/AFN)
- LC-DCP 4.5 broad or LCP 4.5/5 broad
- Large external fixator

1   Introduction
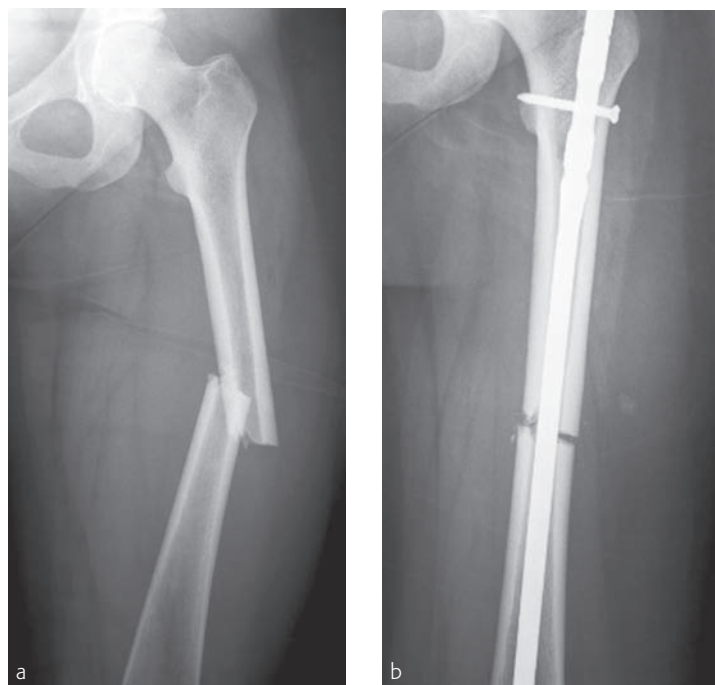
Fig 3.12.1-1a–b
a   Preoperative x-ray: transverse femoral shaft fracture.
b   Postoperative x-ray: stabilization with cannulated femoral nail (CFN).

- Most intramedullary nails in the adult femur fractures are presently inserted in an antegrade direction with reaming of the medullary canal and interlocking.
- The nail entry point has traditionally been in the piriform fossa which allows the implant to curve in just one plane—anteriorly.
- Newer implants have been developed for a trochanteric (tip or lateral) entry point. The trochanter is easier to reach, particularly in obese patients, but requires the implant to have a proximal lateral bend and an anterior bow. The most recent lateral trochanter entry-point nails (expert lateral femoral nail—LFN) have also incorporated the slightly "corkscrew" shape of the natural femur.
- Reaming of the femoral canal is accepted as standard, since there is good evidence that there is less implant failure and a higher and quicker rate of fracture union in comparison with implants inserted without reaming (chapter 2.4.5).
- The use of nails inserted without reaming may still be recommended and/or indicated in a polytrauma patient with significant pulmonary injury and/or if the patient is known to have a cardiac shunt (which may be present in up to 25% of the healthy population).
- Reamers have deep, sharp flutes to reduce overheating of the

canal and subsequent bone necrosis. Some new reamers are even equipped with an irrigation system for direct cooling and an aspiration system to remove bone and marrow debris.

- Reamer shafts that are solid and not "wound wire" reduce the incidence of reamer shaft failure or breakage during reaming as well as problems during cleaning and decontamination.

- Reamers with solid shafts can be reserved to allow disimpaction of a jammed reamer. Reamers with a "wound wire" shaft must never be reversed as this leads to unwinding of the shaft wires and destruction of the reamer shaft.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture: open or closed)
- Implant to be used (with or without reaming)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Traction pin set for distal femoral metaphysis (if fracture table is used)
- Nailing instrument set—CFN
- CFN implant selection

- Synream—reamer set
- Two reaming rods, long, 1150 mm
- Hand reamer set
- Large distractor or external fixator (optional)
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Radiolucent drive

Equipment:
- Standard radiolucent operating table, which may be reconfigured as fracture table
- Table and positioning accessories to assist supine/lateral position and individual position of both legs
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

- Long-lasting postoperative complete pain blocks for the patient with injured leg should be avoided as this could hide symptoms of a subsequent compartment syndrome.

Author   Nigel D Rossiter

4   Patient and x-ray positioning

Femoral nailing can be performed on a fracture table or on a standard radiolucent table in the lateral position. Both set-up methods are described:

Femoral nailing on a fracture table:
- The skin of the distal femur is disinfected.
- Drill a 2 mm K-wire through the distal femoral metaphysis at the level of the top of the patella (so as not to interfere with distal locking for the nail) and attach a traction bow to it.
- Do not use a traction boot on the foot as the foot can slip out.
- Reconfigure the table or transfer the patient to a fracture table.
- Position the legs at different heights, close together. Alternatively, hang the unaffected leg beneath the affected side or elevate it in a padded gutter out of the way (Fig 3.12.1-2).
- If possible reduce the fracture with traction and manipulation before preparing and draping the patient.
- Pad all pressure points carefully (especially in the elderly).
- Place the ipsilateral arm across the chest to be out of way and keep the upper body "windswept" to adduct the hip as much as possible to aid identifying the nail entry point.
- Position the image intensifier on the opposite side of the injury and the operating surgeon.
- Ensure that you can get good-quality AP and lateral x-ray views of the entry point (piriform fossa), fracture site, and distal femur before draping.

Femoral nailing on a standard radiolucent table in supine or lateral position:
- In obese patients it may be technically easier to perform antegrade femoral nailing in a lateral position without skeletal traction.
- Place the patient lateral (or supine with a large sandbag under the ipsilateral buttock) on a radiolucent table.
- Adduct and slightly flex the affected leg anteriorly in front of the unaffected one.
- Position the image intensifier from the opposite side. Check that adequate AP and lateral views can be obtained before draping.
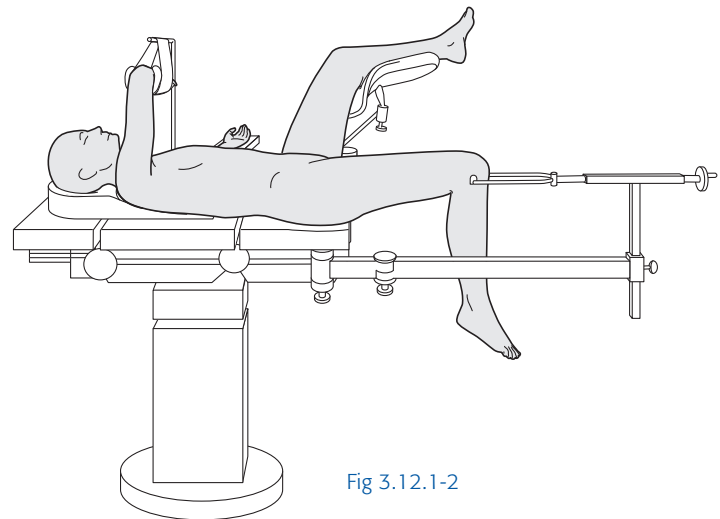
Fig 3.12.1-2

5 Skin disinfecting and draping

- Maintain light manual traction (the assistant may need to stand on a stool) on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the exposed area from above the iliac crest to the mid-tibia with the appropriate antiseptic (Fig 3.12.1-3a).
- Use a single-use exclusion drape (curtain) if the patient is on a traction table (Fig 3.12.1-3b).
- Ensure the adhesive portion of the drape is large enough to reach from the iliac crest to the knee joint to allow distal locking.

- Place the image intensifier on the nonsterile side of the exclusion drape.
- Traditional drapes may be used for both positionings: fracture and standard operating tables. Ensure a waterproof environment for the operative site.
- Drape the image intensifier.
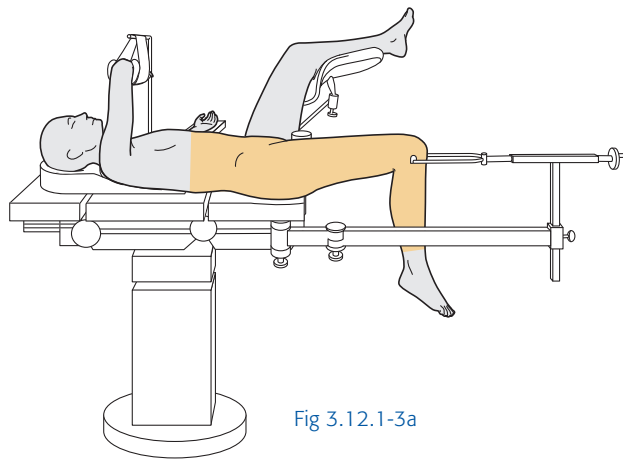
Fig 3.12.1-3a

Fig 3.12.1-3b

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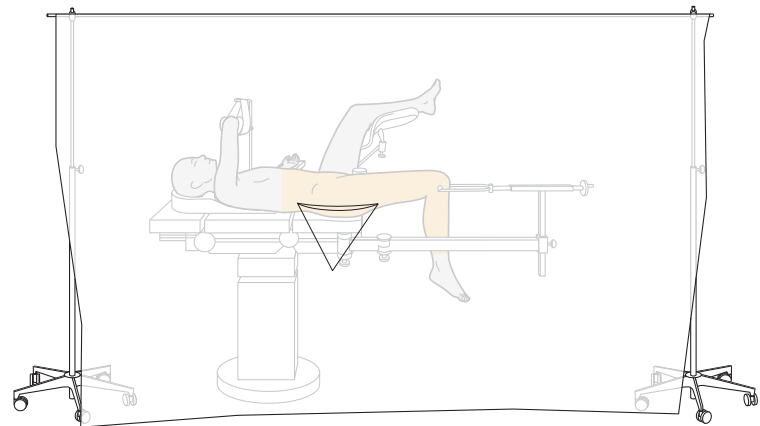
6   Operating room set-up

- Position the operating table (if feasible) within the operating room to allow maximum space on the operating side for the surgeon, staff, and trolleys.
- The surgeon, assistant, and ORP stand on the side of the injury.

- Place the image intensifier on the opposite side of the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.12.1-4).
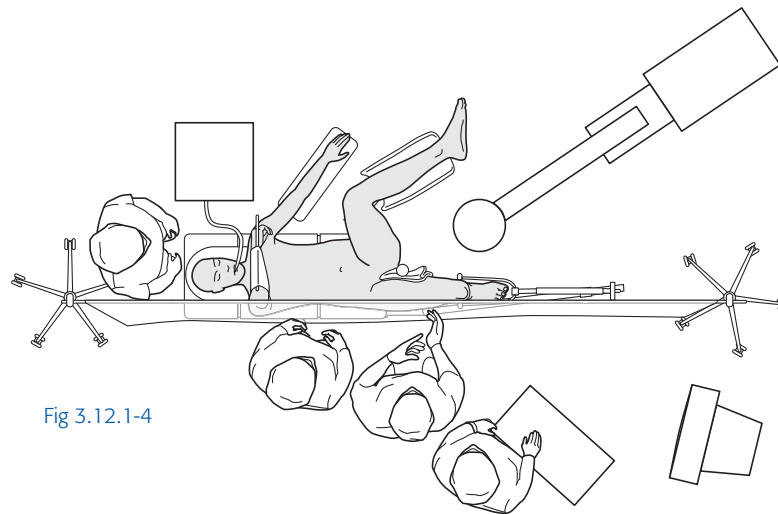
Fig 3.12.1-4

7 Instrumentation
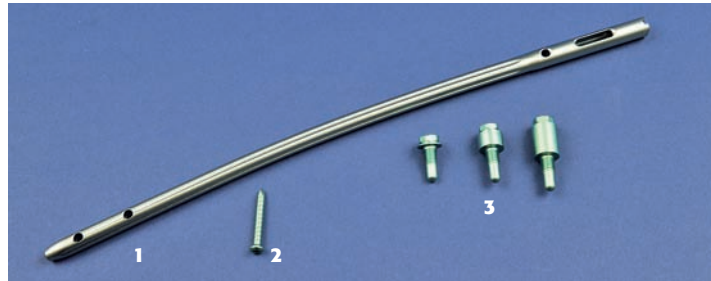
Fig 3.12.1-5a   Implants
1.   CFN
2.   Self-tapping locking bolt 4.9 mm
3.   End caps
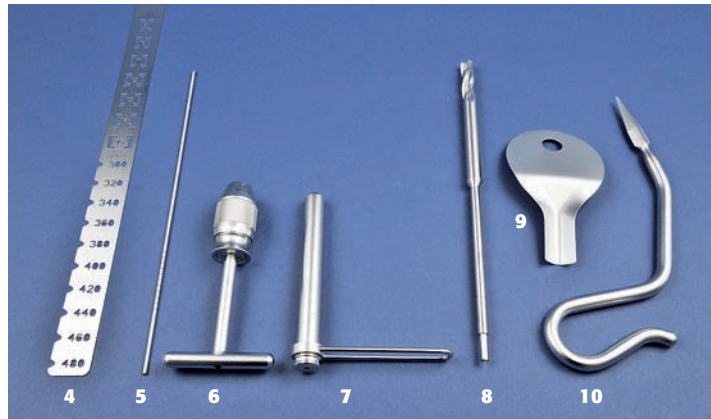
Fig 3.12.1-5b   Instruments for opening of medullary canal and nail size determination
4.   Radiographic ruler
5.   Guide wire 3.2 mm, 300 mm
6.   Universal chuck with T-handle
7.   Double drill sleeve assembly (protection sleeve 17/15 mm and drill sleeve15/3.2 mm)
8.   Cannulated drill bit 13 mm
9.   Tissue protector
10. Awl
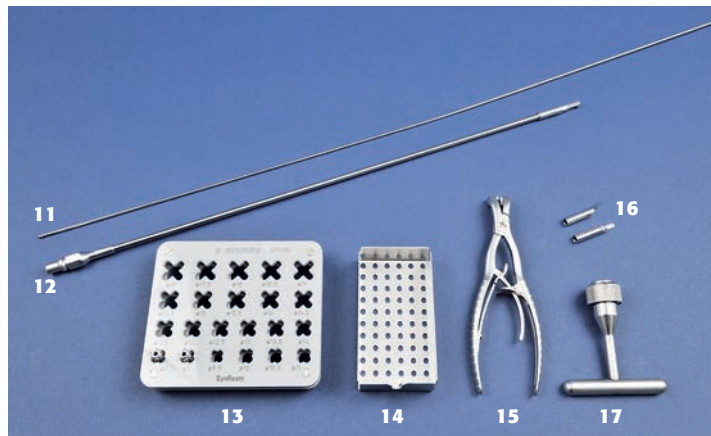
Fig 3.12.1-5c   Instruments for intramedullary reaming
11. Reaming rod 2.5–1150 mm
12. Flexible shaft
13. Tray with reamer heads
14. Removing tool
15. Holding forceps for reaming rod
16. Reduction heads, straight and curved
17. T-handle

Author   Nigel D Rossiter

Fig 3.12.1-5d   Instruments for nail insertion
18.   Insertion handle
19.   Connecting screw
20.   Hexagonal screwdriver with spherical head
21.   Driving cap for CFN
22.   Pin wrench
23.   Hammer
24.   Slide hammer and hammer guide

Fig 3.12.1-5e   Instruments for proximal locking, distal locking, and insertion of end cap
25.   Standard aiming arm for CFN
26.   Triple drill sleeve assembly (protection sleeve 11/8 mm, drill sleeve 8/4 mm, trocar 4 mm)
27.   Calibrated drill bit 4.0 mm
28.   Depth gauge for locking bolts
29.   Screwdriver for locking bolts with holding sleeve
30.   Radiolucent drive
31.   Drill bit 4.0 mm for radiolucent drive
32.   Direct measuring device

Fig 3.12.1-5f   Instruments for implant removal
33.   Screwdriver for locking bolts with holding sleeve
34.   Extraction screw
35.   Pin wrench
36.   Combination wrench 11 mm
37.   Slide hammer
38.   Hammer guide

8   Procedure and technique—step-by-step

Nail insertion and proximal locking

- Check rotation of the opposite uninjured leg before starting.
- Reduce the fracture under the guidance of the image intensifier before preparing and draping. (This may not be possible if the fracture is multifragmentary or unstable).
- Place a short incision proximal to the greater trochanter in line with the femoral shaft.
- Split the muscles, identify the nail entry point by palpation, and insert the 3.2 mm threaded guide wire mounted in the universal chuck with T-handle down to the piriform fossa. Alternatively, use the awl.
- Check its position with the image intensifier. Make sure it lies in the piriform fossa on AP view, and on a "straight line" in direction of the intramedullary canal on both AP and lateral views (Fig 3.12.1-6a–b).
- Mount the double drill sleeve assembly onto the guide wire.
- Open the medullary canal by hand to a depth of 10 cm with the 13 mm cannulated drill bit (for nails larger than 12 mm use a 16 mm broach) over the 3.2 mm guide wire (Fig 3.12.1-6c). Alternatively, use the awl, particularly in obese patients.
- Exchange the cannulated drill bit and guide wire for a ball-tipped reaming rod mounted onto a universal chuck with T-handle.
- Pass the reaming rod into the femoral shaft and guide it across the fracture into the distal end of the femur to the level of the physeal scar.
- If unable to get the reaming rod across the fracture, a cannulated reduction head (straight or curved) attached to a Synream shaft mounted on a T-handle combined with external manipulation of the thigh may be helpful.
- Check the position of the reaming rod in the distal femur on AP and lateral views. Failure to position it in the center of the distal femur will lead to significant varus or valgus malalignment, especially if the fracture is in the distal half of the femur.
- The nail length and diameter are determined under the guidance of the image intensifier with the measuring device.

- Alternatively, determine the length by using two reaming rods of the same length. Place the second reaming rod at the nail entry point. The portion of the second reaming rod beyond the top of the one in the femur defines the length for the nail.
- Start reaming the medullary canal with the front-cutting (8.5 mm) reamer head. Click it onto the flexible shaft and pass it over the reaming rod down the medullary canal.
- Subsequently increase the reamer heads by 0.5 mm increments in size.
- Make sure the reamers are always running forward at full speed and are not stopped, particularly in the mid portion of the diaphysis.
- Prevent the reaming rod from backing out when the reamer head is pulled out of the canal by applying the special rod-holding forceps.
- If the reamer is not advancing adequately, withdraw it (still running) and clean the cutting flutes of the reamer head removing any bone debris before reinserting it.
- During reaming check with the image intensifier that there is no obstruction or loss of reduction.
- Continue reaming until cortical chatter is heard or to a diameter of 1.0 mm greater than the predetermined measured nail.
- Avoid reaming away too much of the cortical bone.
- Confirm the nail dimensions.
- Attach the nail to the insertion handle with the connecting screw. Tighten it with the spherical head screwdriver (Fig 3.12.1-6d).
- Insert the nail over the reaming rod and push it through the reamed canal down to the distal physeal scar. This can be done manually but a hammer is almost always required. Attach the driving cap to the insertion handle, fix it with the pin wrench, insert the hammer guide, and apply gentle blows with the slide hammer (Fig 3.12.1-6e). Never hit the side arm directly.
- Remove the reaming rod and check the reduction clinically (rotation!) and with the image intensifier.

Author   Nigel D Rossiter

- Decide whether to lock proximally or distally first. While it is easier to lock proximally first, it is recommended that distal locking is performed first, as this allows the nail to be slapped back if the fracture is distracted. Also it makes rotational correction easier.
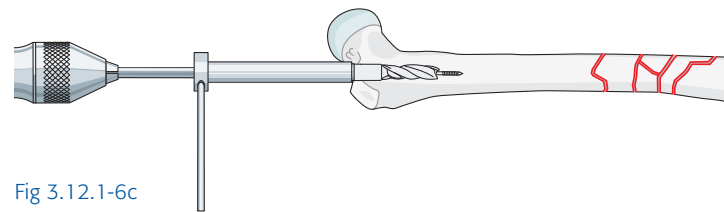
Fig 3.12.1-6c

Fig 3.12.1-6d

a   b
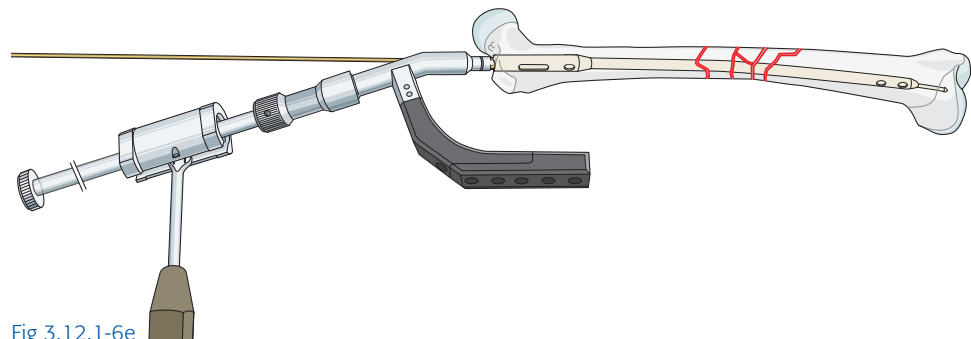
Fig 3.12.1-6a–b

Fig 3.12.1-6e

Distal locking

- Distal locking of the CFN is performed from the lateral side, using the free-hand technique. Using the radiolucent drive facilitates the aiming procedure.
- The number of locking screws required depends on the site and type of the fracture but the insertion of two screws is usual. Move the opposite leg if necessary to allow positioning of the image intensifier.
- Ensure the image intensifier is directed in such a way that the x-ray beam points away from the surgeon's side to the screen on the opposite side.
- Align the C-arm with the hole in the nail closest to the fracture until a perfect circle is visible on the screen (the distal hole is shown in the illustration (Fig 3.12.1-6f–g).

- Do not attempt to adjust the position of the leg to align the holes; this may cause loss of rotational alignment at the fracture. You may, however, tilt the table.
- Place a scalpel blade on the skin over the center of the hole to mark the incision point and make a stab incision.
- Dissect down to the bone using a blunt instrument.
- Position the tip of the corresponding sharp drill bit (4.0 mm) obliquely through the incision. Using the image intensifier place the tip of the drill bit over the center of the hole. Hold it there firmly (Fig 3.12.1-6h).
- Ensuring that the sharp drill bit tip does not move on the bone, the angle of the drill bit is changed until it is exactly aligned with the beam center of the image intensifier beam (Fig 3.12.1-6i).
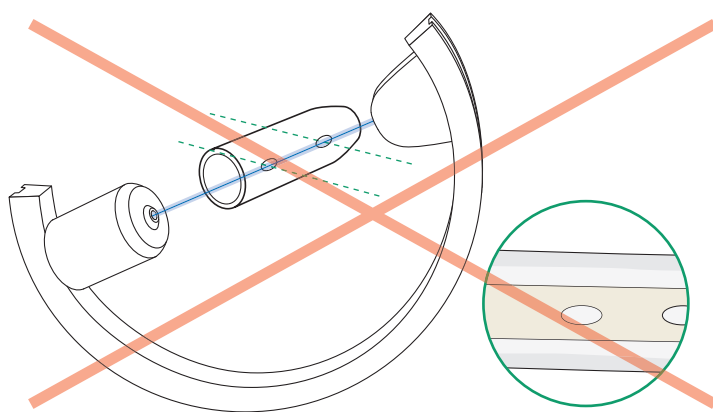
Fig 3.12.1-6f

Fig 3.12.1-6g

Author   Nigel D Rossiter
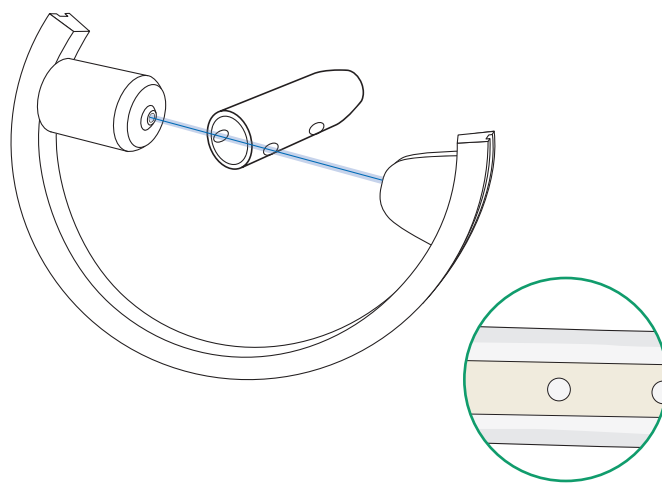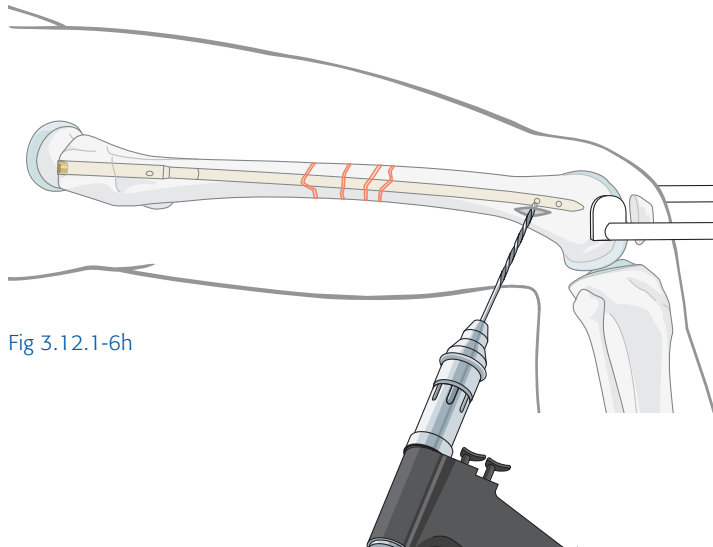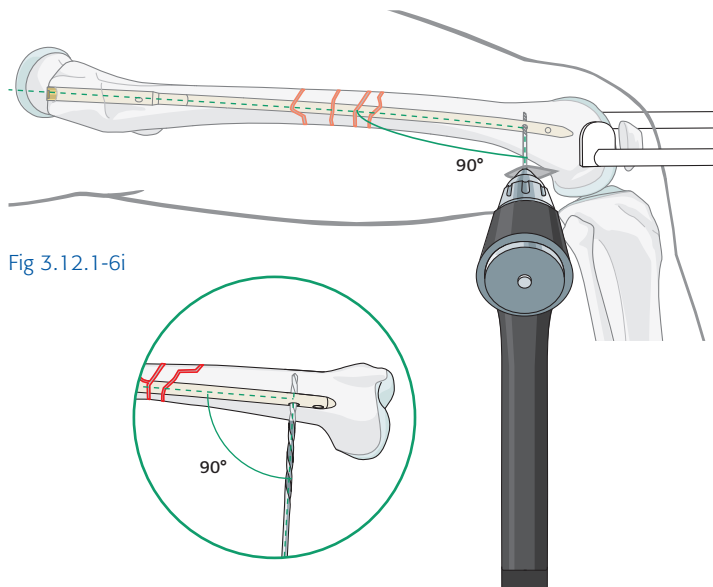
Fig 3.12.1-6h

Fig 3.12.1-6i

- Now drill—without slipping on the bone surface—the hole of the near cortex.
- Stop drilling and manually guide the drill bit through the hole in the nail before drilling the far cortex.
- If no sharp-tipped drill bit is available, it may be easier to indent the bone over the center of the hole in the nail with a short Steinmann pin and a hammer using the same method before attempting to drill a hole. This reduces the risk of the drill slipping on the bone when drilling is initiated.
- Disconnect the drill bit from the drill and verify under guidance of the image intensifier that the drill bit lies within the hole of the nail.
- Measure the screw length using the depth gauge. Ensure the outer sleeve is in contact with the bone and the hook grasps the far cortex.
- If the drill has depth calibrations the length can be read off from the drill bit directly. If necessary this should be checked with the image intensifier.
- Insert the appropriate length (4.9 mm) locking screw using the screwdriver and the holding sleeve, if needed. The holding sleeve grips the locking screw to prevent losing it in the soft tissues.
- Verify the screw length under the guidance of the image intensifier.
- Insert a second screw using the same technique. A minimum of two screws should be used for distal locking.
- Many surgeons leave the drill bit used to drill the first distal locking screw hole in the bone to aid drilling of the second drill hole.
- The drill bit allows the surgeon to determine the correct direction of insertion of the drill bit used to drill the second hole. They will be parallel.

Proximal locking

- Before proximal locking ensure that the fracture is reduced.
- Ensure that rotation is correct using the image intensifier. The intensifier should show that the width of the cortices and the width of the bone is the same both side of the fracture.
- Any gaps at the fracture site should be corrected by slapping back on the nail using the slotted hammer. This will pull the distal fragment which is secured to the nail by the distal locking bolts proximally.
- Take care not to apply too much force as the distal locking bolts can break.
- Monitor the procedure using the image intensifier. This is the last opportunity to make any corrections.
- Insert the triple drill sleeve assembly through the desired hole in the aiming arm, make a stab incision in the skin, and push the sleeves down to the bone.
- Remove the trocar.

- Pass a 4.0 mm calibrated drill bit through the drill sleeve and drill through both cortices of the femur.
- Read off the screw length from the calibrated drill bit just before it penetrates the far cortex (Fig 3.12.1-6j).
- Remove the drill bit and inner drill sleeve.
- Alternatively, use the measuring device, reading the measurement from the top end of the protection sleeve. Add 2 mm to ensure that the screw thread engages in both cortices.
- Select the appropriate length and size of the locking screw.
- Insert the locking screw through the protection sleeve using the screwdriver (Fig 3.12.1-6k). The tip of the locking screw should not project more than 1–2 mm beyond the far cortex.
- Place a second locking screw using the same technique if static locking is desired.
- Check the screw position and length with the image intensifier.
- Remove the insertion handle.
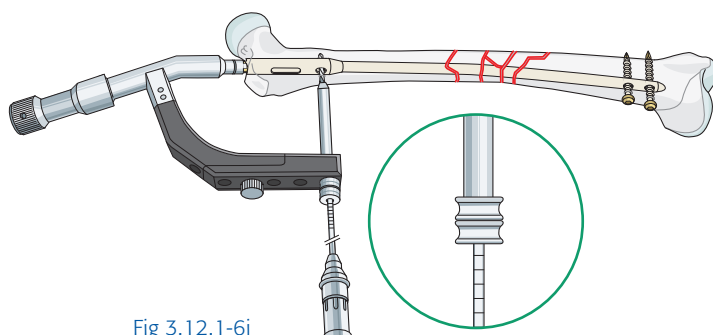
Fig 3.12.1-6j

Fig 3.12.1-6k

Author   Nigel D Rossiter
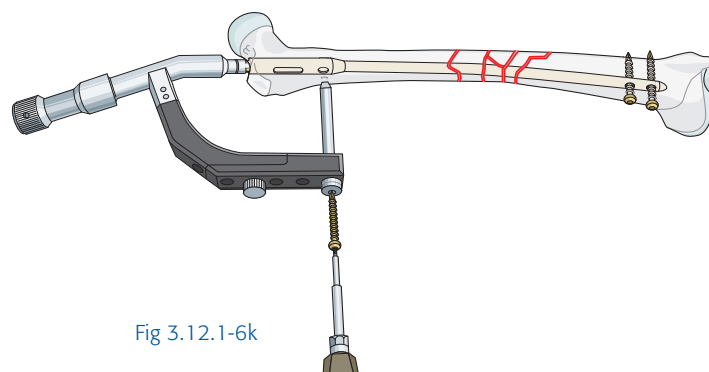
Insertion of end cap

- The size of the end cap depends on how deeply the nail has been inserted into the femur.
- After insertion the top of the end cap should be flush with the femur.
- Remove the aiming arm, the connecting screw, and the insertion handle.
- Insert and tighten the end cap with the screwdriver.
- In obese patients insertion of the end cap is difficult because it is hard to align the screwdriver used for end-cap insertion and the nail itself. In such cases the end cap may become detached from the screwdriver and retrieval may be surprisingly complex. Placing an absorbable suture around the end cap and leaving a long end to hold against the screwdriver handle during insertion gives a stronger grip of the screwdriver to the end cap. It also makes retrieval easier and cross-threading of the end cap into the recess on the upper end of the nail less likely.

- Take final x-rays to ensure that all locking screws are correctly inserted and the fracture is well aligned.
- Close all the wounds.
- Remove all drapes and check the appearance of the operated limb with the other side. Ensure that the ranges of rotational movement at the hip joints are symmetrical, which they should be in the absence of hip pathology. Asymmetry means that the fracture has been fixed with a rotational deformity. The most common malalignment seen in femoral nailing is malrotation. This can only be corrected by removal of the proximal locking bolts and manipulating the femur. It is far better to carry out this procedure at the time of primary surgery even though this means again preparing and draping than to discover the problem later on when surgery may not be so easy. Delayed diagnosis and treatment is also difficult to explain to the patient.

Further information is available on AO Teaching video 20203: The Cannulated Femoral Nail (CFN) and Synream.

9   Specific perioperative care

- Be prepared for the distal femoral metaphysis traction set up.
- Take care of the pressure areas, especially in the elderly.
- Check that the patient is secured on the operating table. Considerable forces may be applied when trying to reduce the fracture which can cause a poorly secured patient to move.

- Ensure that the image intensifier arm does not touch the body, and maintain sterility as it is rotated around the surgical field.
- Ensure sharp instruments do not penetrate the exclusion drape if it is being used.

10   Specific postoperative care

- Take postoperative x-rays unless the intraoperative views are adequate.
- Encourage the patient to regain hip and knee movement as quickly as possible.
- Allow early weight bearing depending on the patient's general condition and the stability obtained by the surgery.
- Postoperative thromboprophylaxis is usual.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Prepare the traction set first if a fracture table is used.
- Check that the full range of instruments and implants are available.
- The large distractor may be used.
- Have two identical reaming rods available for intramedullary nail length measurement.
- Have hand reamers available (just in case).
- Check reamer heads for damage and ensure all cutting flutes are sharp.
- Ensure the surgeon gets the reamers in the correct order of ascending size.
- Confirm the agreed measurement for the nail and locking screws with the surgeon.
- Flush and preclean all cannulated instruments carefully.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Reduce the fracture as accurately as possible before draping.
- Take time to find the correct entry site for nail insertion in both planes as it is impossible to adjust once reaming has started. Failing to get the right entry point makes the rest of the operation difficult and can lead to malalignment and even to a crack or fracture in the proximal femur.
- Keep the reamer running at all times when reaming the diaphyseal area.
- Make sure the reamer always runs in forward and never in reverse.
- Do not force a nail into the canal—if it is too tight ream up another 0.5 mm, or downsize the nail diameter.
- Remove the guide wire before inserting the locking screws.
- Check rotation of the leg before locking and at the end of the procedure.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.12.2 Diaphyseal adult femoral fracture (32-C3): stabilization with distal femoral nail (DFN)

Surgical management

- Indirect reduction and retrograde nailing with distal femoral nail (DFN)

Alternative implants

- Antegrade, cannulated femoral nail (CFN)
- Antegrade solid femoral nail (UFN)
- LC-DCP 4.5 broad or LCP 4.5/5 broad
- Distal femoral locking plate/LISS

1 Introduction
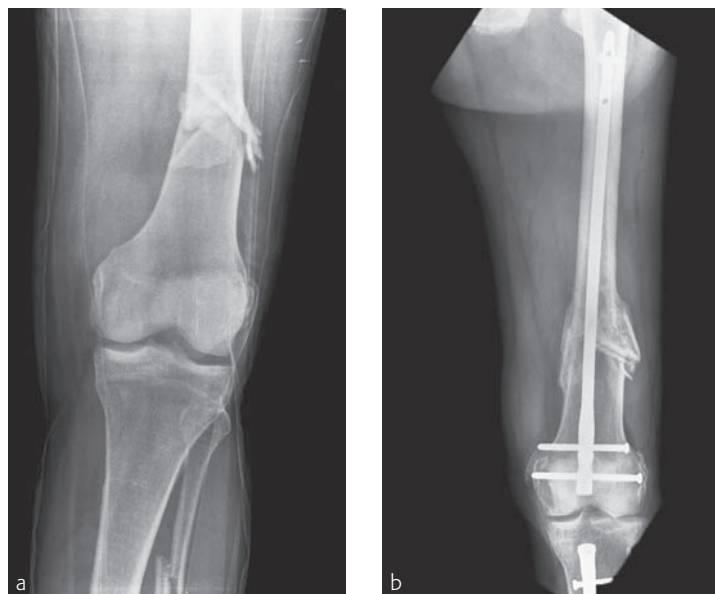
Fig 3.12.2-1a–b
a   Preoperative x-ray: multifragmentary fracture of distal end of femoral shaft.
b   Postoperative x-ray: stabilization with distal femoral nail (DFN).

- Retrograde femoral nailing is an alternative to antegrade nailing for most middle- and distal-third diaphyseal femoral fractures.
- Concern that an approach through the knee joint causes long-term damage has so far proved to be unfounded.
- Some distal femoral nails have been designed angle anteriorly and distally near the knee or come with a slight bow shaped to allow an entry point as low on the trochlea and as near to the notch as possible to minimize articular damage.
- Reaming of the femoral canal is accepted as the standard as there is good evidence that there is less implant failure and a higher and quicker rate of fracture union in comparison with unreamed implants.
- Unreamed implants may still be advised and/or indicated in a polytrauma case with significant pulmonary injury and/or if the patient is known to have a cardiac shunt (which may be present in up to 25% of the healthy population).
- Modern reamers now have deep sharp flutes to reduce the incidence of overheating of the canal and subsequent bone necrosis.

- Indications for use of DFN include:
  - Obese patients with femoral diaphyseal fractures with difficulty of proximal access
  - Associated pelvic and acetabular fractures
  - Femur neck and shaft fractures
  - Floating knee injuries where through one incision both femur and tibia can be nailed
  - Polytrauma with bilateral and ipsilateral leg fractures
  - Pregnancy
  - Associated patella fracture requiring fixation

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed)
- Implant to be used (with or without reaming)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Nailing instrument set—DFN
- DFN implant selection

- Synream—reamer set
- Two reaming rods, long, 1150 mm
- Hand reamer set (optional)
- Large distractor or external fixator (optional)
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Radiolucent drive

Equipment:
- Standard radiolucent operating table
- Table and positioning accessories to assist supine position and individual position of both legs
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- If a spinal anesthetic is used, the surgeon and anesthetist need to be confident that the procedure will not last more than 1.5 hours.
- Long-lasting postoperative complete pain blocks for the injured leg should be avoided as this could hide symptoms of a subsequent compartment syndrome.

Author   Nigel D Rossiter

4   Patient and x-ray positioning

- Position the patient supine with roll or well padded sandbag under the thigh to keep the knee in a flexed position (Fig 3.12.2-2).
- Carefully pad all pressure points, especially in the elderly.
- Position the image intensifier on the opposite side of the injury and the surgeon.
- Before preparing and draping, ensure good AP and lateral image intensifier views can be obtained.
- If manual traction is required to reduce the fracture, try to achieve this before preparing and draping the patient.
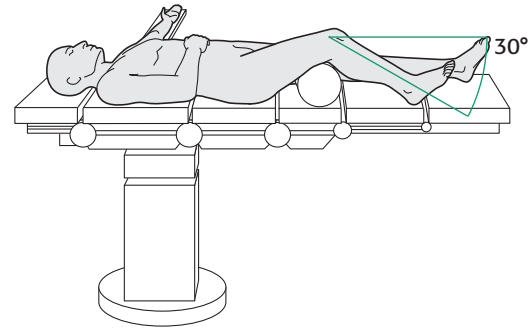
Fig 3.12.2-2

5   Skin disinfecting and draping

- Maintain light manual traction (the assistant may need to stand on a stool) on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the exposed area from above the iliac crest to the foot with the appropriate antiseptic (Fig 3.12.2-3a).
- Drape the limb with a single-use U-drape. A stockinette covers the lower leg and is fixed with a tape (Fig 3.12.2-3b). The leg is draped so as to be freely moved.

- Flex the knee over a well padded post.
- Drape the image intensifier.
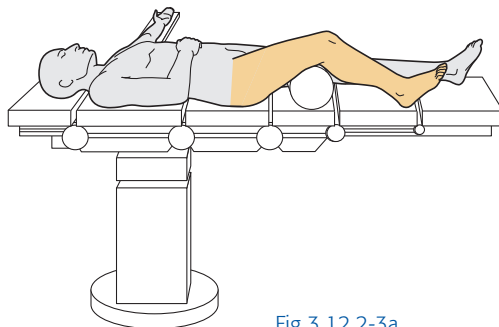
Fig 3.12.2-3a

Fig 3.12.2-3b

6 Operating room set-up

- The surgeon and ORP stand on the side of the affected limb.
- The assistant stands next to the surgeon.
- Place the image intensifier on the opposite side of the injury and the display screen in full view of the surgical team and the radiographer (Fig 3.12.2-4).

Fig 3.12.2-4

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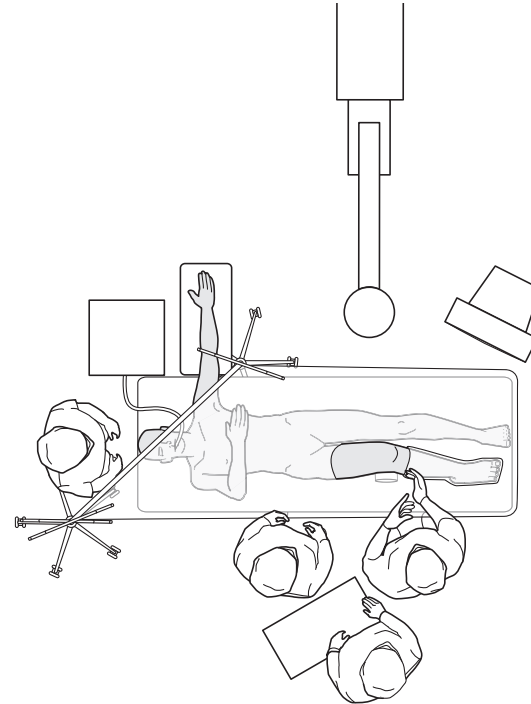
7   Instrumentation
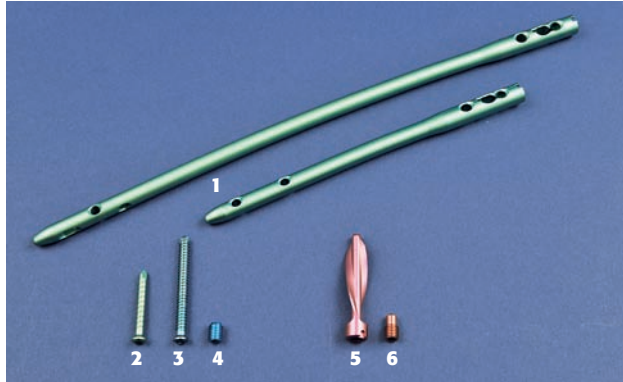
Fig 3.12.2-5a   Implants
1.   DFN, long and short
2.   Locking bolt 4.9 mm
3.   Locking screw 6.0 mm
4.   End cap for nail when using locking screw
5.   Spiral blade for DFN
6.   End cap for nail when using spiral blade
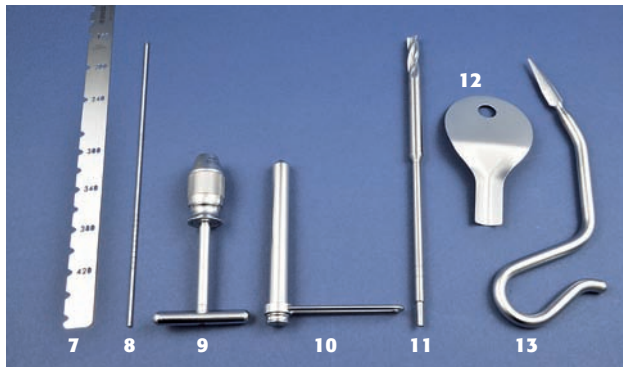
Fig 3.12.2-5b   Instruments for opening of medullary canal and nail size determination
7.   Radiographic ruler
8.   Guide wire 3.2 mm, 300 mm
9.   Universal chuck with T-handle
10.   Double drill sleeve assembly (protection sleeve 17/15 mm and drill sleeve 15/3.2 mm)
11.   Cannulated drill bit 13 mm
12.   Tissue protector
13.   Awl
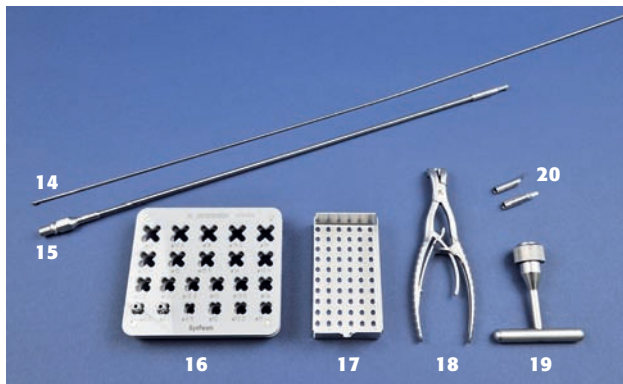
Fig 3.12.2-5c   Instruments for intramedullary reaming
14.   Reaming rod 2.5–1150 mm
15.   Flexible shaft
16.   Tray with reamer heads
17.   Removing tool
18.   Holding forceps for reaming rod
19.   T-handle
20.   Reduction heads, straight and curved

Fig 3.12.2-5d   Instruments for nail insertion
21.   Guide rod
22.   Insertion handle for DFN
23.   Connecting screw
24.   Pin wrench
25.   Slide hammer
26.   Hammer

Fig 3.12.2-5e   Instruments for proximal locking, distal locking, and insertion of end cap
27.   Standard aiming arm for DFN
28.   Triple drill sleeve assembly
         (protection sleeve 11/8 mm,
         drill sleeve 8/4.9 mm, and trocar 4.9 mm)
29.   Calibrated drill bit 4.9 mm
30.   Depth gauge for locking bolts
31.   Screwdriver for locking bolts
32.   Radiolucent drive
33.   Drill bit 4.0 mm for radiolucent drive
34.   Direct measuring device

Fig 3.12.2-5f   Instruments for implant removal
35.   Screwdriver for locking bolts with holding sleeve
36.   Extraction screw
37.   Guide rod
38.   Combination wrench 11 mm
39.   Pin wrench
40.   Slide hammer

Author   Nigel D Rossiter

8   Procedure and technique—step-by-step

- Check rotation of the opposite uninjured leg.
- If possible reduce fracture beforehand using manual traction and confirm with the image intensifier in two planes.
- Make a 4–6 cm longitudinal incision just medial to the medial border of the patella.
- Divide the medial patellar retinaculum and the capsule of the knee joint in the line of the skin incision to enter the knee.
- Gently retract the patella laterally.
- Flex the knee to about 30–45° over the roll to allow access to the intercondylar notch.
- The entry point is in the long axis of the femoral shaft, just above the femoral notch (Fig 3.12.2-6a). Check the entry point using the image intensifier.
- Open the femoral canal by inserting a 3.2 mm guide wire mounted in the universal chuck (Fig 3.12.2-6b). Use of the double drill sleeve is optional.

- Check the position of the guide wire in two planes with the image intensifier. A perfect position of the guide wire is critical. The wire should be central in the distal femur in the AP view. The wire must be aligned with the long axis of the femoral diaphysis in both planes.
- Use the protection sleeve with the 13 mm cannulated drill bit and drill to a depth of 30 mm to create the nail entry canal (Fig 3.12.2-6c). Alternatively, make the entry hole with a sharp awl.
- Remove the guide wire.
- Insert the reaming rod mounted on the universal chuck with T-handle and pass it across the fracture site under the guidance of the image intensifier.
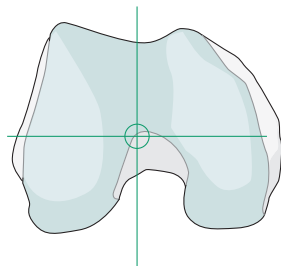
Fig 3.12.2-6a
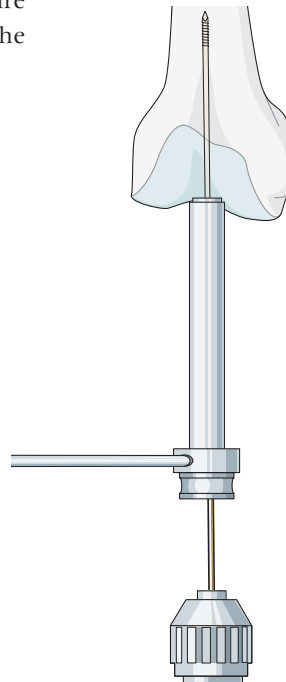
Fig 3.12.2-6b
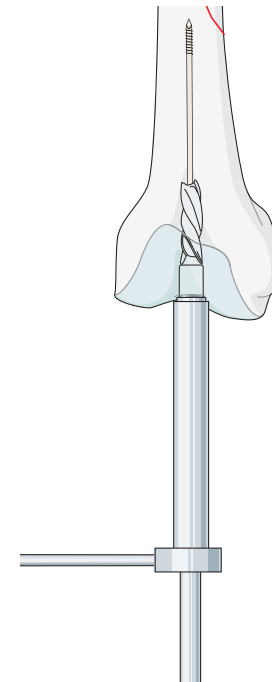
Fig 3.12.2-6c

- If unable to get the reaming rod across the fracture, use a cannulated reduction head (straight or curved), attached to the Synream shaft and the T-handle combined with manipulation of the fracture.
- Determine the nail length using a second reaming rod of the same length to the nail entry point. The portion of the second guide wire beyond the one in the femur defines the length. Alternatively, take extramedullary measurements for nail length and diameter with the radiographic ruler under the guidance of the image intensifier.
- Start reaming the medullary canal with the front-cutting (8.5 mm) reamer head. Click it onto the flexible shaft and pass it over the reaming rod down the medullary canal.
- Make sure the reamers are always running forward at full speed and are not stopped, particularly in the mid portion of the diaphysis.
- Subsequently, ream in 0.5 mm increments until cortical chatter is heard.
- Ream up to midway between the lesser and greater trochanter.
- Prevent the reaming rod from backing out when the reamer head is pulled out of the canal by applying the special rod-holding forceps.
- If the reamer is not advancing adequately, withdraw it (still running) and clean the cutting flutes of the reamer head removing any debris before reinserting it.
- Make sure that there is no obstruction or loss of reduction during reaming by using the image intensifier.
- Continue reaming until cortical chatter is heard or to a diameter of 1.0 mm greater than the predetermined measured nail. Avoid reaming away too much of the cortical bone.
- Select a DFN of the appropriate size and diameter.
- Slide the connecting screw through the insertion handle and tighten the nail with the pin wrench. The aiming arm attachment should lie on the lateral side of the leg (Fig 3.12.2-6d).

- Attach the aiming arm to the insertion handle and check if the drill sleeve assembly meets the locking holes in the nail. Remove aiming arm.
- Insert the nail over the reaming rod until the end of the nail is buried beneath the articular surface at the intercondylar notch (Fig 3.12.2-6e).
- Check reduction and nail position. (Aim for the nail end to be just above "Whiteside's Line" on a lateral image intensifier view.)
- Remove the reaming rod.
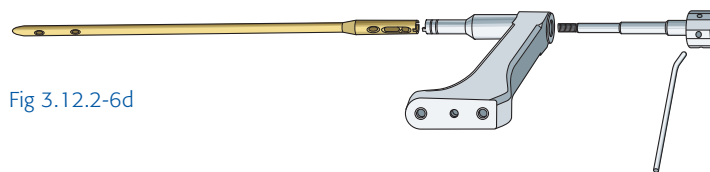
Fig 3.12.2-6d

Fig 3.12.2-6e

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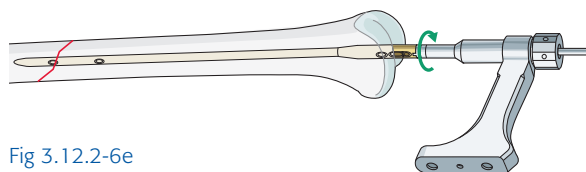
Distal locking

- Distal locking is normally performed first.
- Attach the aiming arm.
- Pass the drill sleeve assembly with trocar through the appropriate hole of the insertion handle and make a stab incision.
- Dissect bluntly down to the bone and press the drill sleeve with trocar down against the bone.
- Remove the trocar and insert the 4.9 mm drill bit which is advanced to touch but not penetrate the far cortex (Fig 3.12.2-6f).
- Read off the length for a 6.0 mm locking screw from the calibrated drill.
- Determine a screw length that will not quite penetrate the far cortex of the femoral condyle. Screws that protrude from the medial side of the distal femur produce irritation of the overlying soft tissues.

- Remove the drill bit and inner sleeve and insert the selected 6.0 mm locking screw (turquoise) with the screwdriver (Fig 3.12.2-6g).
- Insert a second 6.0 mm locking screw using the same technique.
- There is the option to insert a spiral blade instead of the most distal locking screw. This is used in supracondylar femoral fractures and in patients with poor-quality bone.
- Check the position and length of the locking screws with the image intensifier.
- Check fracture reduction and rotation of the distal fragment before proximal locking.
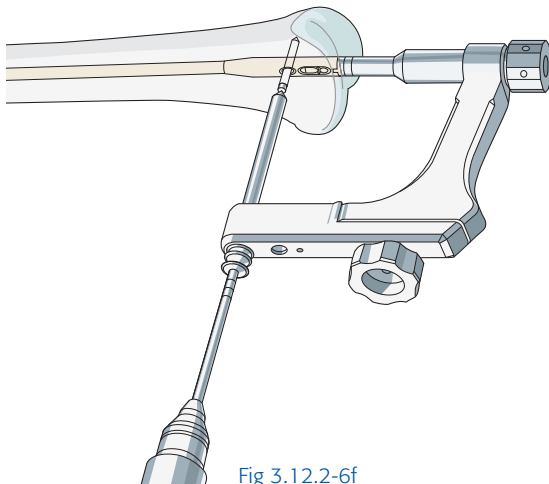
Fig 3.12.2-6f
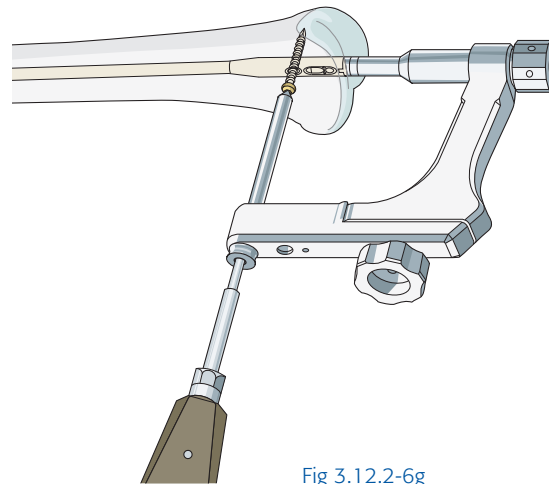
Fig 3.12.2-6g

Proximal locking

- For proximal locking position, place the image intensifier in perfect AP direction over the proximal femur as the locking holes are running from anterior to posterior.
- Ensure the image intensifier screen is placed as close as possible to the underside of the operating table to allow the maximum space between x-ray source and the thigh for drilling in AP direction.
- Adjust the image intensifier until one of the locking holes looks perfectly round (Fig 3.12.2-6h–i).
- Do not attempt to adjust the position of the leg to align the holes; this may cause loss of rotational alignment. You may however tilt the table.
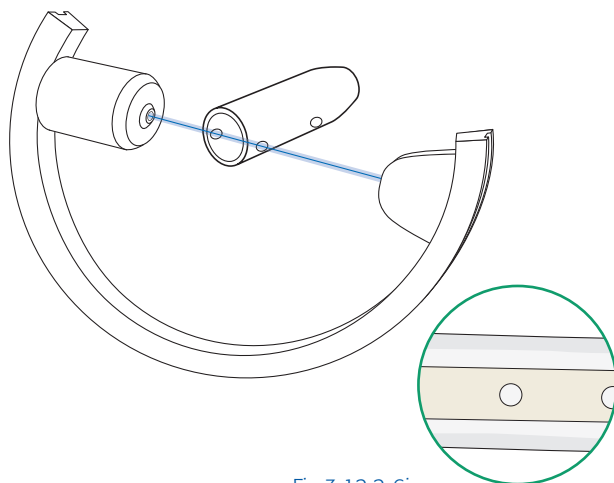
- Use the handle of an instrument placed over the skin to determine the site of the hole and make a stab incision.
- Dissect bluntly down to the bone.
- Mount a 4.0 mm sharp-tipped short drill bit on the drill.
- Position the tip of the drill bit obliquely through the incision onto the bone (Fig 3.12.2-6j). Using the image intensifier, maneuver the tip of the drill exactly over the center of the locking hole.
- Making sure the sharp drill tip does not skid on the bone, change the angle of the drill until it is exactly aligned with the direction of the image intensifier beam (Fig 3.12.2-6k).
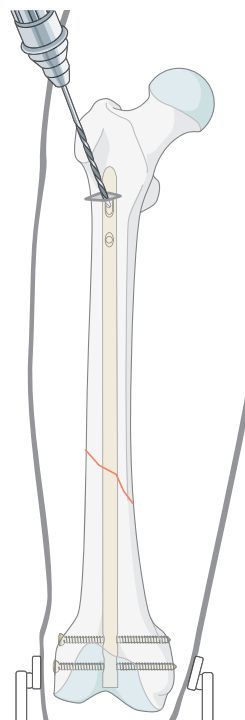
Fig 3.12.2-6i

Fig 3.12.2-6j

Fig 3.12.2-6k

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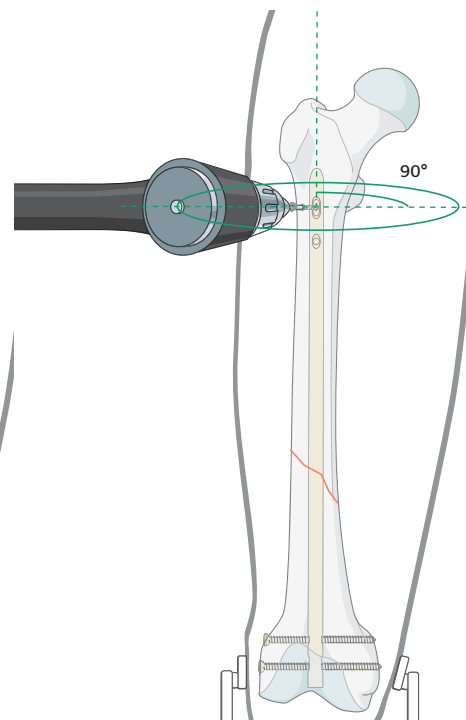
- Drill through the anterior cortex of the femur. Manually rotate the drill to insert it through the hole in the nail and then drill the far (posterior) cortex.
- Measure the length of the required screw either by reading it directly from the drill bit or by using the depth gauge.
- With a radiolucent drive the same technique is used. The radiolucent drive has the advantage of being able to observe the drill bit with the image intensifier while drilling, which makes it easier.
- Insert a 4.9 mm locking screw (green) of appropriate length.
- If no holding sleeve for the screwdriver is available, tie an absorbable suture around the neck of the screw and leave a long end to hold against the screwdriver handle during insertion. This will aid screw retrieval if the drill hole is missed and the screw plunged past the femur into the posterior soft tissues.
- On an AP view a locking screw correctly placed in a round (static) hole in the nail should leave no part of the hole visible. A second locking screw is placed using the same technique. Normally, proximal locking should have a minimum of two screws.

- Take and save copies of final x-rays in both planes.
- Close the wounds.
- Remove all drapes and check the appearance of the operated limb with the other side. Ensure that the ranges of rotational movement at the hip joints are symmetrical, wich they should be in the absence of hip pathology. Asymmetry means that the fracture has been fixed with a rotational deformity. The most common malalignment seen in femoral nailing is malrotation. This can only be corrected by removal of the proximal locking bolts and manipulating the femur. It is far better to carry out this procedure at the time of primary surgery even though this means again preparing and draping than to discover the problem later on when surgery may not be so easy. Delayed diagnosis and treatment is also difficult to explain to the patient.

Further information is available on AO Teaching video 20200: Distal Femoral Nail (DFN); video 40088: Implantation Method for the Distal Femoral Nail (Supported by Arthroscopy).

9   Specific perioperative care

- Make sure the patient is secured on the operating table so that he/she does not move when traction is applied.
- Take care of pressure areas, specially in the elderly.

- Maintain sterility as the image intensifier is rotated around the body.

10   Specific postoperative care

- Take postoperative x-rays for documentation unless image intensifier views are adequate.
- Allow early weight bearing as tolerated.

- Encourage the patient to regain hip and knee movement as quickly as possible.
- Perioperative thromboprophylaxis is usual.
- Keep in mind that the use of nonsteroidal antiinflammatory drugs may slow fracture healing.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Have two identical reaming rods available for intramedullary nail length measurement.
- Confirm the agreed measurement for the nail with the surgeon.
- Be aware there are two sizes of a locking screw.
- Check reamer heads for damage and ensure all cutting flutes are sharp.
- Ensure the surgeon gets the reamers in the correct order of ascending size.
- Flush and preclean all cannulated instruments carefully.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Reduce the fracture as much as possible before draping.
- Make sure to identify the correct entry site for the nail placement in both planes.
- Ensure the guide wire is perfectly positioned before reaming.
- Do not stop reaming in diaphyseal area.
- Ensure the reamer is always running forward and never in reverse.
- Do not force the nail into canal—if it is too tight, ream up another 0.5 mm or downsize nail diameter.
- Remove the reaming rod before inserting the locking screws.
- Check rotation of the leg before locking.
- Check rotation of the leg at the end of the procedure and correct any detected rotational malalignment at time of primary surgery.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Nigel D Rossiter

3.12.3   Diaphyseal pediatric femoral fracture (32-A): stabilization with titanium elastic nails (TENs)

Surgical management

- Indirect reduction and stabilization with titanium elastic nails (TENs)

Alternative implants

- LC-DCP or LCP, dimension depending on age of child
- External fixator

---

1   Introduction

- Femoral fractures in children require some form of stabilization but have a higher remodeling potential than those in adults.
- The presence of open growth plates rules out the use of conventional intramedullary nails.
- TENs are suitable for use in long-bone fractures in children whose medullary canal is large enough to accommodate them.
- In femoral fractures this applies to children older than 3 years.
- TENs should always be used in pairs of nails of the same diameter.

Fig 3.12.3-1a–b
a   Preoperative x-ray: transverse fracture of femoral shaft in a child.
b   Postoperative x-ray: stabilization with titanium elastic nails (TENs).

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Titanium elastic nail set
- General orthopaedic instrument set (smaller versions depending on age of child)

Equipment:
- Radiolucent operating table
- Traction table can be used, if required; but access to both sides of the leg is required
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

Author   Nigel D Rossiter

3   Anesthesia

- This procedure is usually performed with the patient under general anesthesia.

4   Patient and x-ray positioning

- Position the patient supine.
- Use a pillow to elevate the leg slightly (Fig 3.12.3-2).
- Secure small patients to the operating table so they do not move when traction is applied to the leg.
- Bring the image intensifier in from the opposite side of the injury.
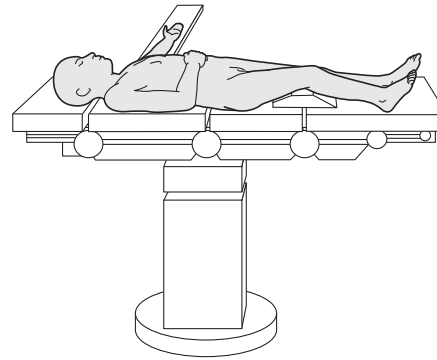
Fig 3.12.3-2

5 Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the exposed area from above the iliac crest to the foot with the appropriate antiseptic (Fig 3.12.3-3a).

- Drape the limb with a single-use U-drape. A stockinette covers the lower leg and is fixed with a tape (Fig 3.12.3-3b).
- Drape the leg so as to be freely movable.
- Drape the image intensifier.
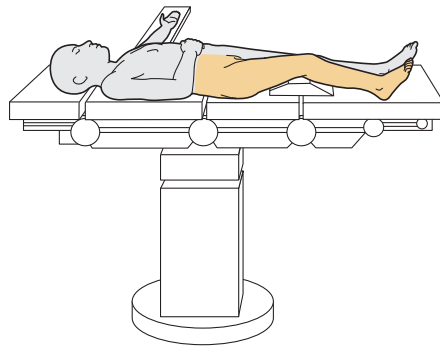
Fig 3.12.3-3a
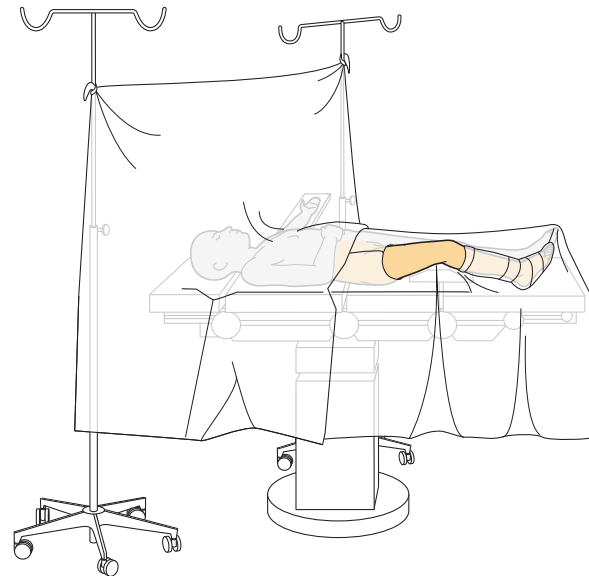
Fig 3.12.3-3b

Author   Nigel D Rossiter

6   Operating room set-up

- The surgeon and ORP stand on the side of the injury.
- The assistant stands at the foot of the table to apply traction to reduce the fracture.
- Place the image intensifier on the opposite side of the injury and the display screen in full view of the surgical team and the radiographer (Fig 3.12.3-4).
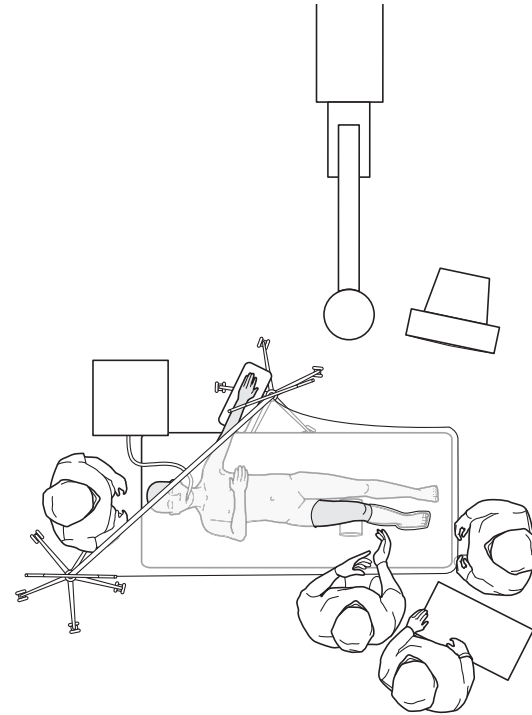
Fig 3.12.3-4

7 Instrumentation
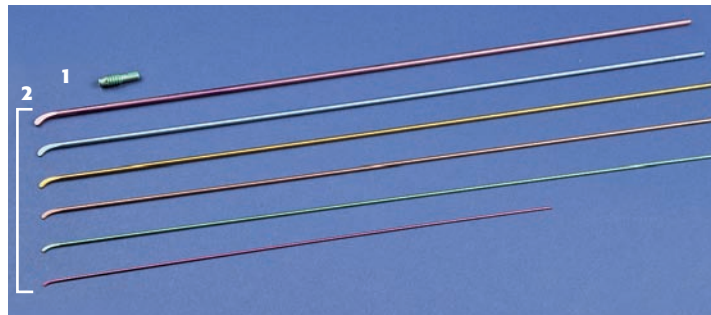
Fig 3.12.3-5a   Implants
1.   End cap (only for TEN 3.0–4.0 mm)
2.   TEN 1.5–4.0 mm

Fig 3.12.3-5b   Instruments for opening of intramedullary canal and nail insertion
3.   Awl for TEN
4.   Inserter for TEN
5.   Pin wrench
6.   Hammer guide for TEN
7.   Impactor, curved
8.   Impactor, straight
9.   Combined hammer
10.   Cutter for TEN (two elements)
11.   Screwdriver shaft for end cap

Fig 3.12.3-5c   Instruments for implant removal
12.   Extraction pliers
13.   Hammer guide for TEN
14.   Slide hammer

Author   Nigel D Rossiter

8   Procedure and technique—step-by-step

- Check rotation of the opposite uninjured leg.
- Reduce the fracture if possible and confirm reduction with the image intensifier in two planes.
- Determine the nail diameter: each should be one third of the diameter of the intramedullary canal. Always use two identical nails.
- The length of the nail is from the insertion point to the level of the greater trochanter.
- Prebend both nails so that the apex of the curve lies at the level of the fracture site when inserted and the curve is such that the tips of the nail lay about three times the diameter of the medullary canal from the apex (Fig 3.12.3-6a).
- Ensure that the flat nail tips lie in the plane of the curve of the nail.
- For distal nail insertion each nail should both be contoured in the same way.

- Identify the insertion site about 1–2 cm above the distal epiphysis, both on the medial and lateral side using the image intensifier.
- Make a short incision starting with the lateral side; bluntly dissect down to the bone.
- Open the medullary canal with the awl by making an initial small hole perpendicular to the bone, and then angling the instrument in a proximal direction. Enlarge the hole as the awl is advanced (Fig 3.12.3-6b).
- Mount the first nail in the inserter with about 10 cm of nail protruding from the chuck. The flat nail tip should point toward the longer arm of the inserter handle to help orientation during insertion. (Align markers on the end of the nail made with lasers with marks on the inserter).
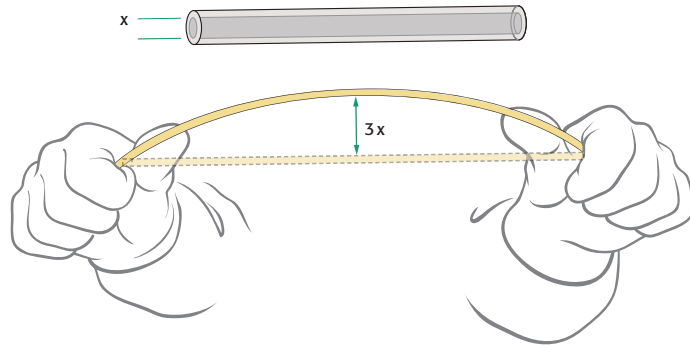
Fig 3.12.3-6a

Fig 3.12.3-6b

533
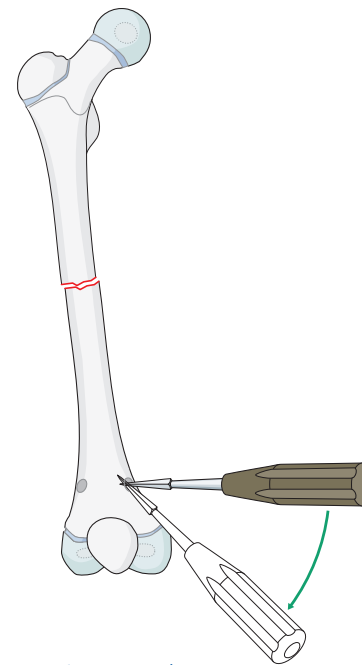
- Insert the nail into the bone with the nail tip at 90º to the shaft, and then rotate the inserter through 180º so the tip lies parallel to the shaft pointing proximally (Fig 3.12.3-6c).
- Advance the nail to the level of the fracture and confirm the position with the image intensifier.
- Insert the second nail using the same technique from the medial side and advance it to just below the fracture site (Fig 3.12.3-6d).
- Advance the nails manually by gently twisting the inserter handle back and forth or by hitting the striking surface of the inserter with gentle taps of a hammer. The T-piece must not be struck.
- With the fracture held reduced, push the first nail a short way across the fracture site (Fig 3.12.3-6e).

- If the fracture is not reduced manipulate the distal fragment using the two inserted nails as joysticks. Alternatively, use the F-shaped reduction tool applied externally to reduce the fracture and hold it in place while the nails are passed across the fracture. If the fracture cannot be reduced with either of these maneuvers, perform an open reduction through a small incision centered over the fracture site.
- When both nails have crossed the fracture site, advance them fully into the proximal femur so that their tips lie between the lesser and greater trochanters. The nail tips should not cross any growth plates.
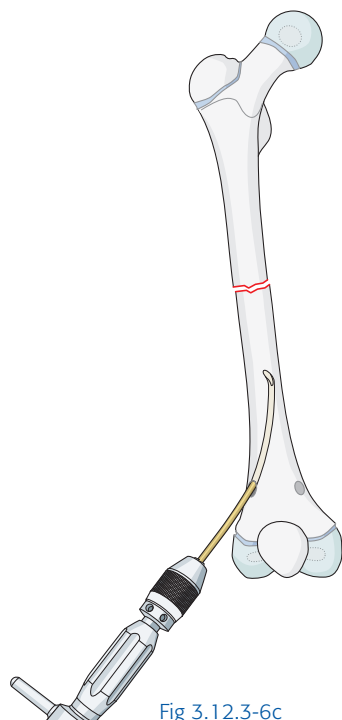
Fig 3.12.3-6c
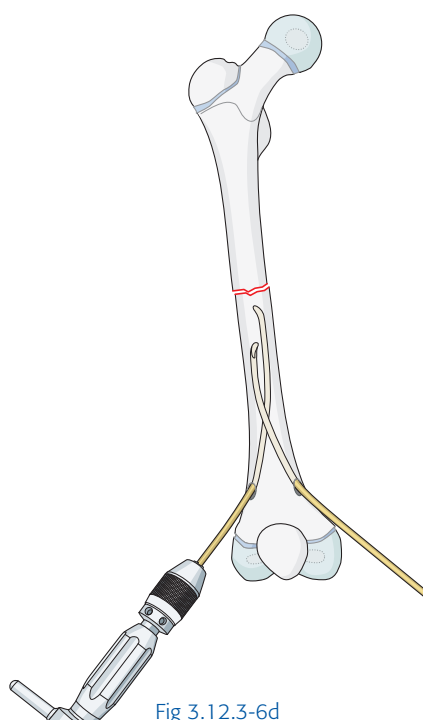
Fig 3.12.3-6d

Fig 3.12.3-6e

Author   Nigel D Rossiter
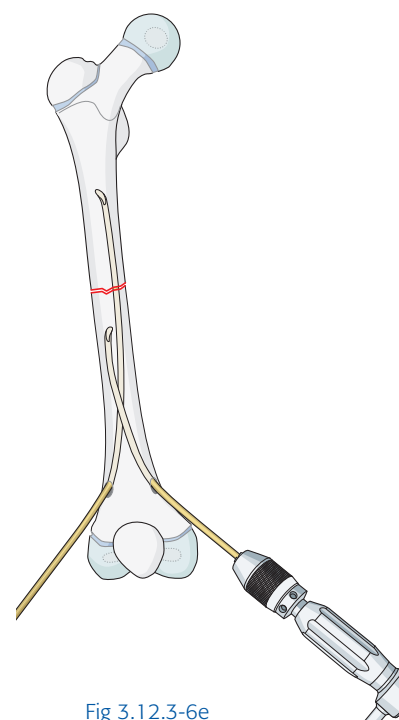
- Check the rotational alignment of the femur, the fracture reduction, and the nail positions with the image intensifier in both planes.
- Trim the nails using the cutter for TEN, leaving about 2 cm of nail protruding from the bone to facilitate nail removal (Fig 3.12.3-6f).
- Final seating and bending of the nails is achieved with the different impactors.
- The ends of the nail are bent away from the bone to facilitate nail removal.
- Blunt end caps to screw over the sharp nail ends are available (for TEN 3.0–4.0) to protect the soft tissues. They should also prevent the nail-tip migration (Fig 3.12.3-6g).

- Take and save copies of final x-rays in both planes.
- Remove all drapes and check the appearance of the operated limb with the other side. Ensure that the ranges of rotational movement at the hip joints are symmetrical. Rotational malalignment will not correct with growth; therefore any malreduction must be corrected at the time of initial surgery.
- Close the wounds.

Further information is available on AO Teaching video 40096: Elastic Stable Intramedullary Nailing in Children.

Fig 3.12.3-6f

Fig 3.12.3-6g
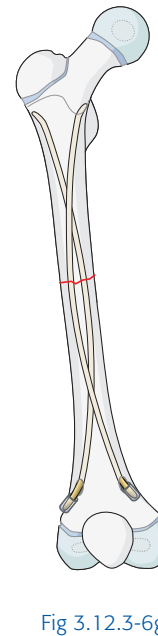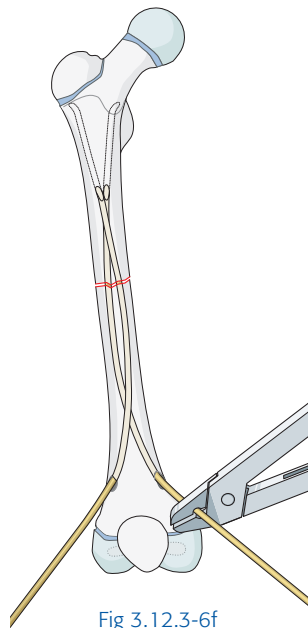
9 Specific perioperative care

- Make sure the patient is secured on the operating table, as considerable force can be applied when trying to reduce the fracture.
- Take care of pressure areas, specially in the elderly.
- Maintain sterility as the image intensifier is rotated around the body.

10 Specific postoperative care

- Take x-rays postoperatively to document the fixation unless saved image intensifier views are adequate.
- Mobilization is at the surgeon's discretion. Restricted weight bearing is usually required and children normally progress to full weight bearing around 6 weeks.
- Encourage the children to regain hip and knee movement. Knee movement can be uncomfortable and may take some weeks to recover.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check that at least three TENs of each size are available.
- Have additional universal chuck with T-handle available.
- Consider F tool for reduction.
- Remember end caps are only available for TENs 3.0–4.0 mm.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Reduce fracture as much as possible before draping.
- Always use nails in pairs of the same diameter.
- Ensure nails are correctly prebent and mounted in the inserter.
- A universal chuck with T-handle can be used on the second nail to enable both nails to be manipulated at the same time.
- Do not rotate nails more than 180° or they can wind around each other.
- Do not leave nail ends too long or they will cause skin irritation.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.13 Distal femoral fractures

Author   Ian Harris

3.13   Distal femoral fractures

Implants and surgical technique

- 95° Condylar blade plate for adults
- Locking compression plate for distal femur (LCP-DF 4.5/5.0)
- Dynamic condylar screw and plate (DCS)

Cases

- Extraarticular distal femoral fracture (33-A2)
- Intraarticular distal femoral fracture (33-C2)
- Intraarticular distal femoral fracture (33-C2)

Introduction

- The Müller AO/OTA Classification divides distal femoral fractures into three groups:
  – type 33-A: extraarticular fractures
  – type 33-B: partial articular fractures
  – type 33-C: complete articular fractures
- Extraarticular distal femoral fractures occur most frequently in elderly patients with osteoporosis who have a simple fall and an indirect fracture mechanism.
- In younger patients, intraarticular fractures mainly result from high-energy injuries caused by a direct blow to the leg. The fractures are often open and patients frequently have multiple injuries.
- The treatment priorities for displaced distal femoral fractures are similar to those of other articular fractures, ie, to anatomically reduce and stabilize the articular surface and to restore overall alignment of the limb. Achievement of these principles should allow adequate return of function and a satisfactory long-term outcome.
- Undisplaced stable fractures may in exceptional circumstances be treated nonoperatively.
- Extraarticular fractures (type 33-A) can be fixed with a retrograde femoral nail (DFN) or a fixed-angled plate construct such as a

95°condylar blade plate or a dynamic compression screw (DCS). The distal femoral precontoured locking plates (LISS or LCP-DF) may also be used but are generally reserved for more complex intraarticular fracture patterns (type 33-C).
- Partial intraarticular fractures require accurate reduction and stable fixation, usually with lag screws and/or a buttress plate. These fractures are uncommon.
- Complete intraarticular fractures require anatomical reduction and rigid fixation of the articular component, usually with lag screws. The method of fixation of the metaphyseal component of the fracture depends on the fracture pattern. Simple fractures are generally best managed with anatomical reduction and rigid fixation, but although more complex ones require restoration of length, axial and rotational alignment, accurate reduction of every bone fragment is usually not necessary. They may be bridged with either a fixed-angled plate construct or a retrograde nail.
- Any surgical fracture treatment should achieve correct alignment (length, rotation, and angulation) and articular congruity as well as stable fixation to allow early knee motion to regain function and a normal gait. Restoration of the correct axis of the limb will reduce the risks of developing posttraumatic osteoarthrosis.

Müller AO/OTA Classification—distal femur

| 33-A1 | 33-A2 | 33-A3 | 33-B1 | 33-B2 | 33-B3 | 33-C1 | 33-C2 | 33-C3 |

33-A   **extraarticular fracture**
33-A1   simple
33-A2   metaphyseal wedge and/or fragmented
         wedge
33-A3   metaphyseal complex

33-B   **partial articular fracture**
33-B1   lateral condyle, sagittal
33-B2   medial condyle, sagittal
33-B3   coronal

33-C   **complete articular fracture**
33-C1   articular simple, metaphyseal simple
33-C2   articular simple, metaphyseal multi-
         fragmentary
33-C3   articular multifragmentary

Author   Ian Harris

3.13.1   Extraarticular distal femoral fracture (33-A2): stabilization with 95° condylar blade plate for adults

Surgical management

- Open reduction and stabilization with 95°condylar blade plate for adults

Alternative implants

- Retrograde intramedullary nail (DFN) (see chapter 3.12.2)
- Dynamic condylar screw (DCS)
- Locking compression plate for distal femur (LCP-DF 4.5/5.0)

1   Introduction
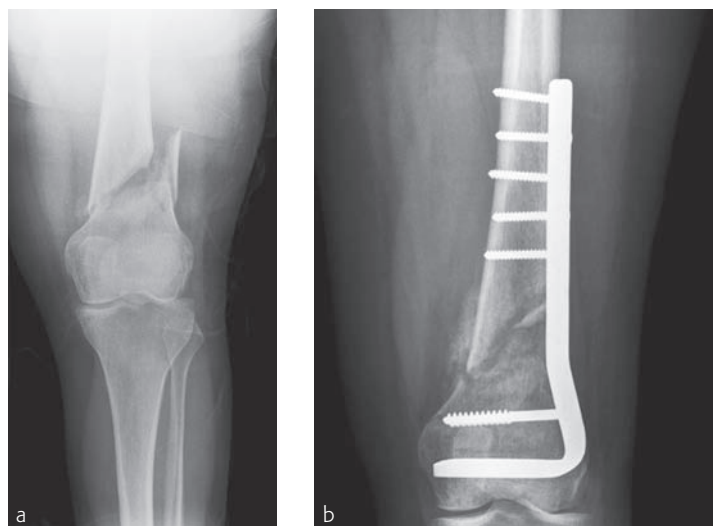
Fig 3.13.1-1a–b
a   Preoperative x-ray: multifragmentary fracture of distal femoral metaphysis.
b   Postoperative x-ray: stabilization with 95° condylar blade plate.

- The 95°condylar blade plate was the first blade plate developed for distal femoral fracture surgery. In some countries this device is still the only implant available. It is still the implant of choice for revision surgery and corrective osteotomies of the distal femur.
- The 95° condylar blade plate is a fixed-angled device, and obtains a good purchase in the distal fragment.
- If the fracture pattern is simple (33-A1), open reduction and direct fixation of the fracture should be performed.
- For higher degrees of metaphyseal comminution (33-A3) indirect reduction and bridging of the fracture focus, without exposing it, is recommended.
- Fixation with a 95°condylar blade plate provides good control of the proximal and distal fragments.
- All conventional plate fixations are dependent on compression between bone fragments and between plate and bone; it may be compromised in patients with osteoporosis and alternative implants (DFN and LCP-DF) may be advised.
- Careful preoperative planning to establish the correct blade entry point, the length of the blade, and the length of the plate required is essential.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:

- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:

- Angled blade plate instrument set
- 95°condylar blade plate implant set
- Basic instrument and screw set 4.5/6.5
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:

- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

Author   Ian Harris

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Position the patient supine on a radiolucent operating table.
- Use a roll to provide knee flexion which reduces the pull of the gastrocnemius muscles on the distal fragment. The pull of these muscles is the major deforming force on the fracture and must be overcome to achieve adequate reduction. Flexion of the knee also permits easy lateral imaging of the distal femur (Fig 3.13.1–2).
- Ensure adequate imaging of the femur from the shaft to the knee in the AP and lateral views.
- A tourniquet may be applied (inflate only when needed) if it does not obstruct the placement of the plate. If in doubt, apply a sterile tourniquet after draping.
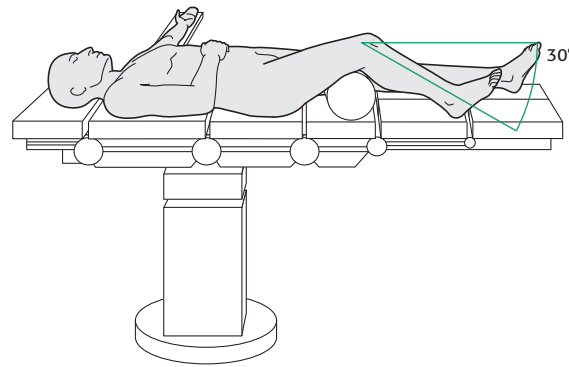
Fig 3.13.1–2

5 Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the whole leg from the hip, including the foot, with the appropriate antiseptic (Fig 3.13.1-3a**).
- Drape the limb with a single-use U-drape or extremity drape. A stockinette covers the foot and lower leg and is fixed with a tape.

- Drape the leg to allow it to be freely moved (Fig 3.13.1-3b).
- Flex the knee slightly over a roll of padding.
- Drape the image intensifier.
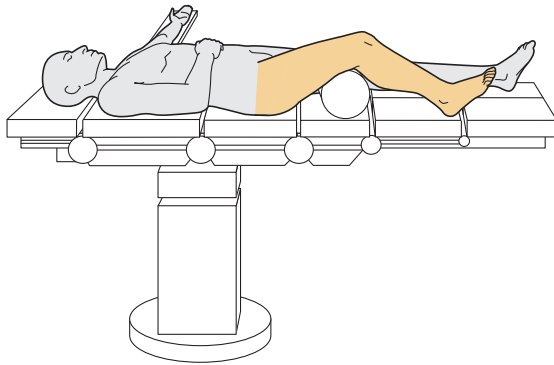
Fig 3.13.1-3a

Fig 3.13.1-3b

Author   Ian Harris

6   Operating room set-up

- The ORP and surgeons stand on the lateral side of the affected limb.
- Position the image intensifier on the opposite side of the table medial to the fracture with the display screen in full view of the surgical team and the radiographer (Fig 3.13.1-4).
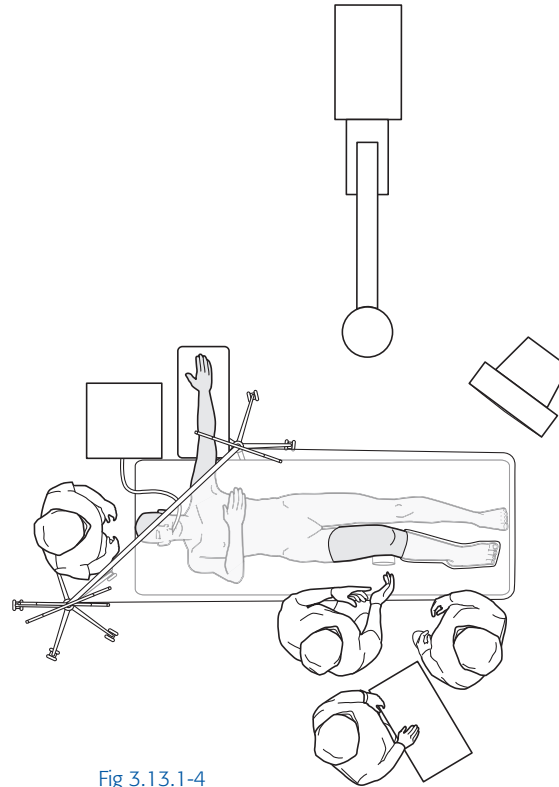
Fig 3.13.1-4

7 Instrumentation
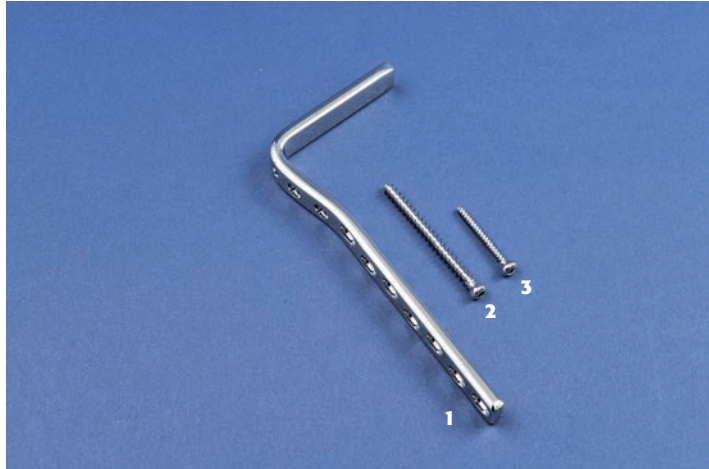
Fig 3.13.1-5a—Implants
1. 95° condylar blade plate, 9 holes
2. Cancellous bone screw 6.5 mm
3. Cortex screw 4.5 mm

Fig 3.13.1-5b—Instruments for opening of lateral cortex (plate seating)
4. Triple drill guide
5. Condylar blade plate guide
6. K-wire 2.0 mm
7. Drill bit 4.5 mm
8. Double drill sleeve 4.5/3.2 mm
9. Router for quick coupling
10. Chisel handle and blade
11. Hammer

Author   Ian Harris

Fig 3.13.1-5c—Instruments for fracture fixation with 95° condylar blade plate
12. Seating chisel and chisel guide
13. Hexagonal screwdriver for large fragment screws
14. Slotted hammer
15. Inserter
16. Socket wrench 11 mm
17. Combination wrench 11 mm
18. Impactor
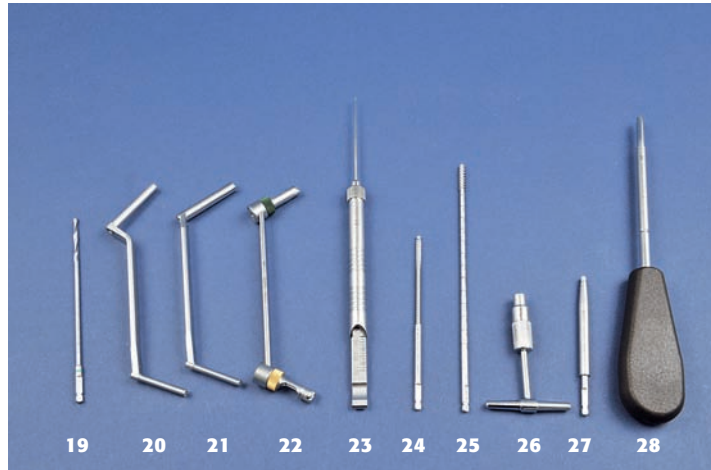
Fig 3.13.1-5d—Instruments for plate fixation
19. Drill bit 3.2 mm
20. Double drill sleeve 4.5/3.2 mm
21. Double drill sleeve 6.5/3.2 mm
22. DCP drill sleeve 4.5 mm
23. Depth gauge
24. Tap 4.5 mm for cortex screws
25. Tap 6.5 mm for cancellous bone screws
26. T-handle
27. Screwdriver shaft
28. Screwdriver

8 Procedure and technique—step-by-step

- Make a lateral longitudinal incision from the level of the knee joint to above the fracture proximally.
- Expose the lateral surface of the femoral condyle, the extraarticular fracture, and the femoral shaft by lifting the vastus lateralis off the lateral intermuscular septum.
- Reduce the fracture using direct manipulation, and temporarily hold the reduction with forceps or K-wires.
- If possible, fix the fracture with interfragmentary 4.5 mm cortical lag screws but continue to reinforce these with a reduction forceps while the blade is inserted, as seating the blade requires some force (Fig 3.13.1-6a).

- Mark the insertion point for the blade 1.5 cm proximal to the knee joint with a chisel, in line with the shaft of the femur, at approximately the junction between the anterior one third and posterior two thirds of the lateral condyle (Fig 3.13.1-6b).
- Use three K-wires for the correct orientation of blade: the first wire (A) marks the plane of the knee joint; the second (B) is placed anteriorly over the two femoral condyles and marks the plane of the patellofemoral joint (Fig 3.13.1-6c), while the third (C) is drilled into the condyles distal to the plate entry site running parallel to the two other wires. Remove the first and second wires.
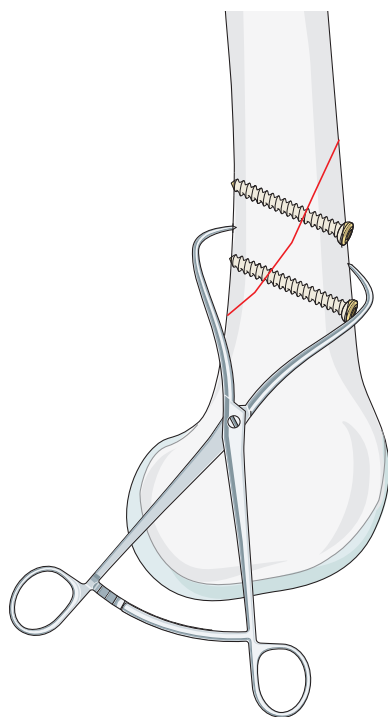
Fig 3.13.1-6a
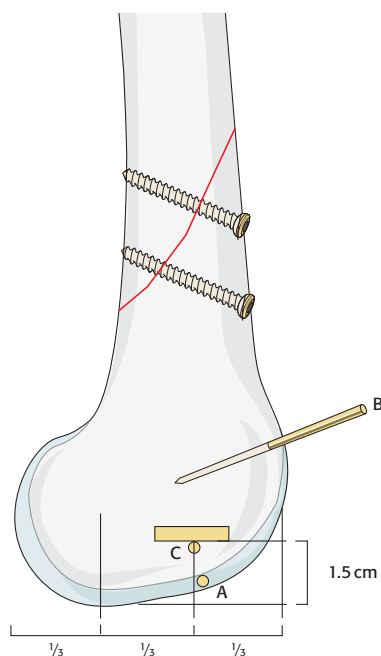
Fig 3.13.1-6b

Fig 3.13.1-6c

Author   Ian Harris
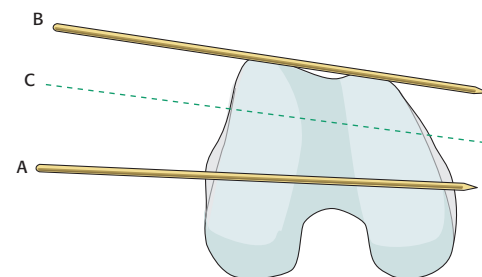
- Place the 95º condylar blade plate guide and the triple drill guide 4.5 mm over the plate entry point and in the direction of the third K-wire just proximal to it (Fig 3.13.1-6d).
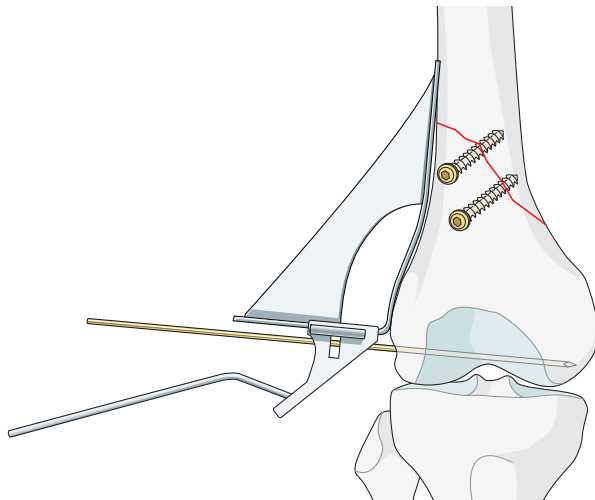
- Insert a 4.5 mm drill bit into the middle hole of the triple drill guide and check its direction with the image intensifier in both planes. It must run parallel to the knee joint line (Fig 3.13.1-6e). If the position is correct remove the power drill leaving the drill bit in place and drill the other two holes with a separate 4.5 mm drill bit. In poor-quality bone it is only necessary to drill the near cortex, whereas in good-quality bone the drill should be advanced well into the cancellous bone.
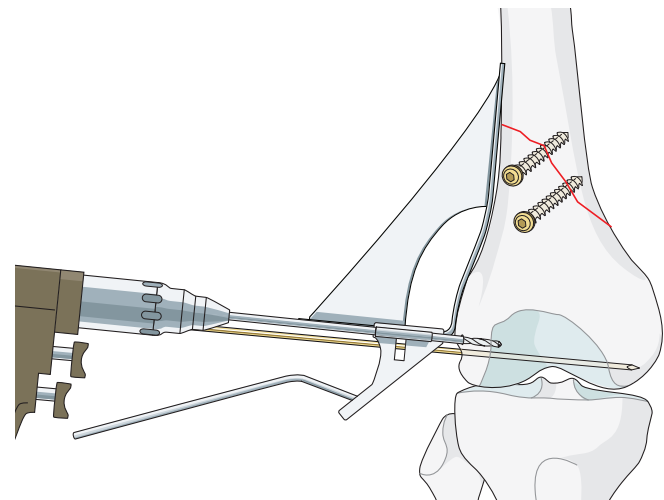
Fig 3.13.1-6d

Fig 3.13.1-6e

- Remove the drill bits and the drill guide and join the 3 holes with the router mounted on a drill to form a slot (Fig 3.13.1-6f).
- Adjust and set the chisel guide to 95°. Using a large-fragment screwdriver, slide it onto the seating chisel.
- Cut a U-shaped path for the blade with the seating chisel using the slotted hammer (Fig 3.13.1-6g).
- Ensure that the chisel guide is held parallel to the femoral shaft in the sagittal and coronal planes.
- Make sure the blade of the seating chisel crosses the femoral condyles parallel to the third K-wire. This will ensure the correct blade position parallel with the knee joint, providing 5° of anatomical valgus.

- Check the correct position of the blade with the image intensifier. The seating chisel must not exit the medial cortex. The length of the blade should be approximately 15–20 cm less than the width of the condyles as seen on an AP x-ray. This is because the width of the condyles as seen on an AP x-ray represents the wide posterior portion of the distal femur while the blade lies in the narrower anterior half. Read the length of the blade directly from the engraved scale on the chisel, where the chisel shaft meets the lateral cortex of the femur.
- Determine the number of holes (length) for the condylar blade plate that will allow adequate fixation in the proximal segment.
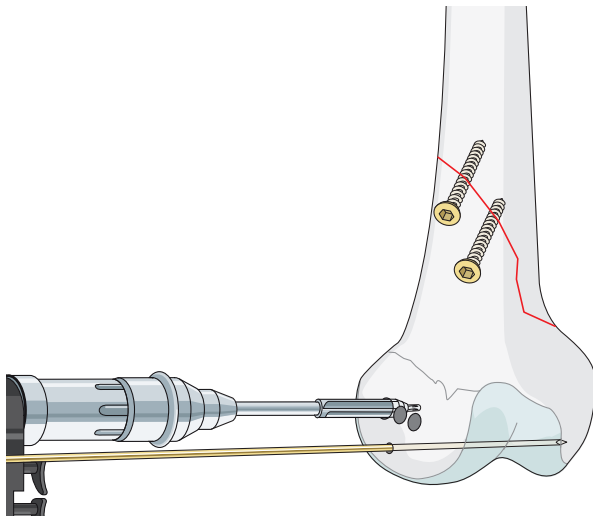
Fig 3.13.1-6f

Fig 3.13.1-6g

Author   Ian Harris
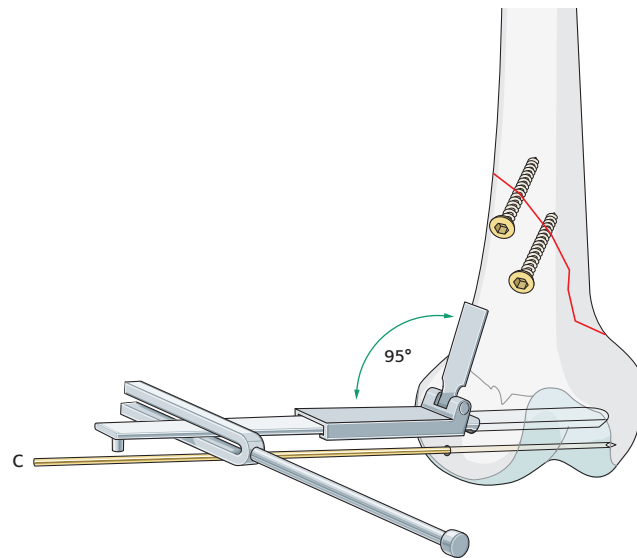
- Select the appropriate 95° condylar blade plate and attach it to the inserter using the combination wrench. Ensure the blade and the inserter are in the same horizontal plane.
- Remove the seating chisel.
- Insert the blade of the plate gently by hand in the correct direction (Fig 3.13.1-6h). Use the slotted hammer and direct blows until the plate rests on the cortex of the lateral femoral condyle. In poor-quality bone make sure that the blade follows the track cut with the chisel by monitoring its insertion using the image intensifier.
- Use the impactor to finally seat the plate.
- You may need to bevel the superior edge of the slot to allow the plate to sit directly on the bone.

- Supplement the distal fixation with one or two 6.5 mm cancellous bone screws inserted parallel to the blade plate. Drill a 3.2 mm hole (Fig 3.13.1-6i), measure the depth, tap the outer cortex, and insert a 6.5 mm fully threaded cancellous bone screw of appropriate length.
- Check again correct fracture reduction and alignment of the condylar blade plate to the femur shaft.
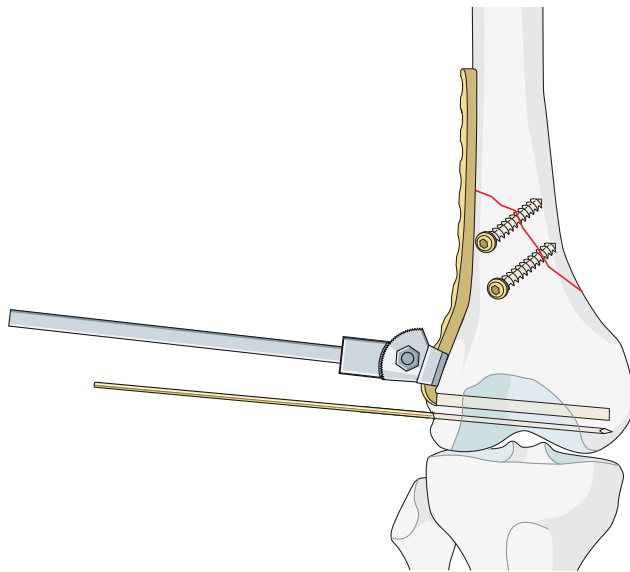
Fig 3.13.1-6h
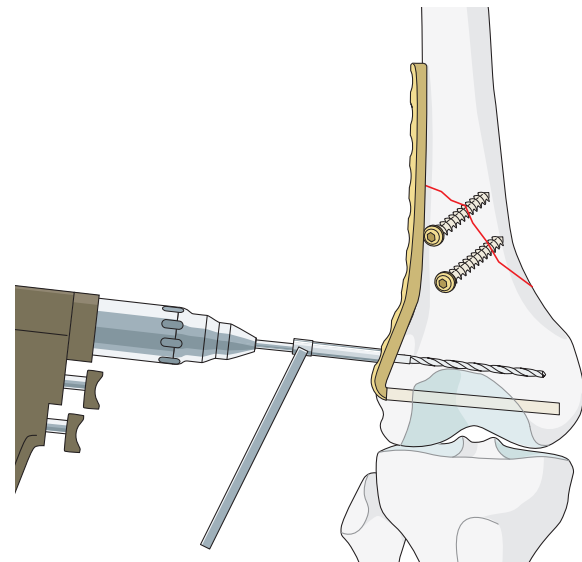
Fig 3.13.1-6i

- If the metaphyseal fracture has been reduced and primarily fixed with lag screws, the plate acts as a protection plate and should be fixed to the shaft proximally with three or four bicortical 4.5 mm cortex screws. Using the 3.2 mm drill guide in the neutral position (green) drill a hole, measure the depth, tap the hole, and insert an appropriate length 4.5 mm cortex screw.
- If the fracture is transverse more compression can be obtained with the aid of the articulated tension device. Using the guide for the articulated tension device, drill a bicortical hole 2 cm proximal to the proximal end of the plate and in line with its screw holes. Use a 3.2 mm drill. Measure the length of the drill hole and add 4 mm to give the correct screw length to be used. Tap the hole using a 4.5 mm tap. Apply the articulated tension device to the end of the plate and couple the device to the bone using a 4.5 mm screw of the correct length through the prepared drill hole. Tighten the screw on the articulated tension device using the combination wrench to obtain compression at the fracture site. The degree of compression can be estimated by reading the colored scale on the device.
- Insert at least three 4.5 mm cortical bone screws in the proximal segment of the plate using the technique described above (Fig 3.13.1-6j).

- Make a final check of fracture reduction, blade and screw position, and length.
- Save images for documentation.
- Close the wound.

Further information is available on AO Teaching video 00064: Condylar Plate Fixation in the Distal Femur.
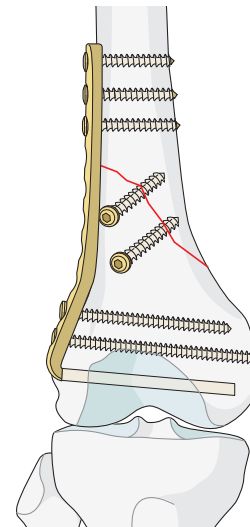
Fig 3.13.1-6j

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9   Specific perioperative care

- Be careful with pressure areas, particularly in the elderly.
- Ensure that imaging access is adequate before disinfecting.
- Maintain sterility when the image intensifier is moved from AP to lateral position.
- Avoid excessive deformity at the fracture site during preparation and draping.

Author   Ian Harris

10   Specific postoperative care

- Perform x-ray documentation by saving the image intensifier films or postoperative x-rays.
- Splinting of the limb should not be necessary unless fixation is poor, or if other injuries are present that require splinting.
- Immediate movement of the knee is encouraged preferably with continuous passive motion.
- Partial weight bearing (10–15 kg) may be started within days, provided the patient is compliant. Full weight bearing should be possible after 8–12 weeks depending on the progress of fracture healing.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check that the blade plate insertion instruments are complete.
- Have a second 4.5 mm drill bit available.
- Confirm with the surgeons the correct setting of the chisel
- guide using the 95° condylar blade plate.
- Make sure when mounting the plate on the inserter that the blade and the inserter are in horizontal alignment.
- Ensure an anterior position of the bolt of the inserter in order to facilitate easy removal of the insertion handle after impacting the blade.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Make a careful preoperative plan before starting and ensure the correct sizes of plates are available.
- Understand the normal anatomy (different axis) of the distal femur and features of the implant.
- Minimize the soft-tissue dissection as much as possible, but ensure that there is adequate exposure to allow reduction and fixation.
- During insertion of the seating chisel and the blade plate, be mindful of the blade alignment in all three planes.
- Ensure a long enough plate is selected to provide adequate fixation of the proximal fragment.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Ian Harris

3.13.2   Intraarticular distal femoral fracture (33-C2): stabilization with locking compression plate for distal femur (LCP-DF 4.5/5.0)

Surgical management	Alternative Implants

- Indirect reduction and stabilization with the locking compression plate for distal femur (LCP-DF 4.5/5.0)

- Less invasive stabilization system (LISS)
- 95° condylar blade plate for adults
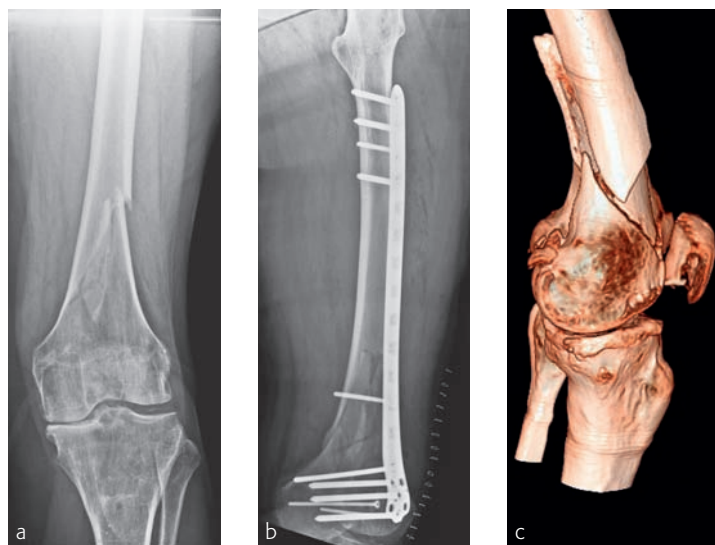- Dynamic condylar screw (DCS)

1   Introduction

Fig 3.13.2-1a–c
a   Preoperative x-ray: multifragmentary distal femoral fracture with intraarticular involvement.
b   Postoperative x-ray: stabilization with locking compression plate for distal femur.
c   3-D CT scan reconstruction showing intraarticular element of fracture.

- The intraarticular component of these fractures requires anatomical reduction and fixation with one- or two-plate independent lag screws, while the metaphyseal comminution can be reduced indirectly and bridged with a percutaneously inserted precontoured internal fixator-type plate—LISS or LCP distal femur (LCP-DF 4.5/5.0).
- The application technique of the LCP with combination-holes or LISS with threaded round holes is similar. The LISS was developed first and uses self-drilling unicortical 5.0 mm locking head screws (LHS) in the shaft of the femur. The combination holes of the LCP version today uses bicortical 5.0 mm self-tapping LHS or if required conventional 4.5 mm cortex screws for the shaft portion of the plate.
- For both plates a radiolucent insertion guide (right/left version) can be used to facilitate LHS insertion.
- Knowledge of the normal orientation of the distal femur to the shaft (5°–9° of valgus) is necessary.
- Fixed-angled implants and especially precontoured locking plates are particularly useful in fractures close to the knee joint or above a prosthesis where there is limited space for bone fixation in the distal segment. They also provide superior fixation in severe osteoporosis.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used (note: plate comes in right and left versions)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Locking compression plate instrument set for distal femur and locking screws 5.0 (LCP-DF 4.5/5.0)
- Basic instrument and screw set 4.5
- Basic instrument and screw set 3.5 (optional)
- K-wire set 1.6–2.0 mm
- Locking compression plates for distal femur (LCP-DF 4.5/5.0), right or left depending on side of injury
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

Author   Ian Harris

4   Patient and x-ray positioning

- Place the patient supine on a radiolucent operating table.
- Use a roll to provide knee flexion which reduces the pull of the gastrocnemius muscles on the distal fragment. The pull of these muscles is the major deforming force on the fracture and must be overcome to achieve adequate reduction (Fig 3.13.2-2a). Flexion of the knee also permits easy lateral imaging of the distal femur.
- Ensure adequate imaging of the femur from the shaft to the knee in the AP and lateral views (Fig 3.13.2-2b–c).
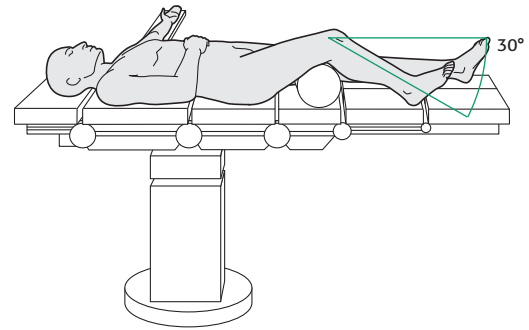
Fig 3.13.2-2a
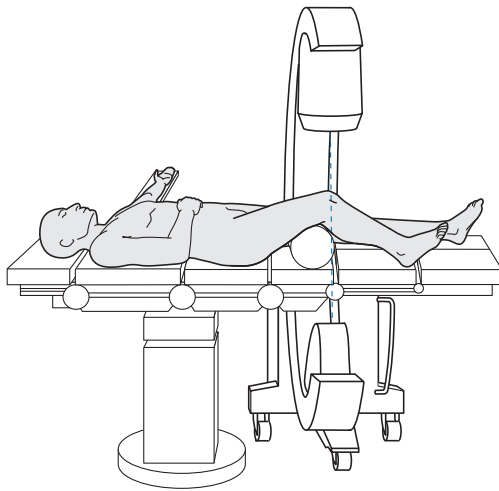
Fig 3.13.2-2b
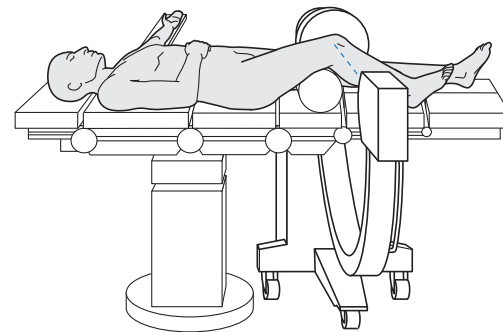
Fig 3.13.2-2c

5 Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the whole leg from the hip including the foot with the appropriate antiseptic (Fig 3.13.2-3a).
- Drape the limb with a single-use U-drape or extremity drape. A stockinette covers the foot and lower leg and is fixed with a tape.

- Drape the leg to allow it to be freely moved (Fig 3.13.2-3b).
- Flex the knee slightly over a roll of padding.
- Drape the image intensifier.
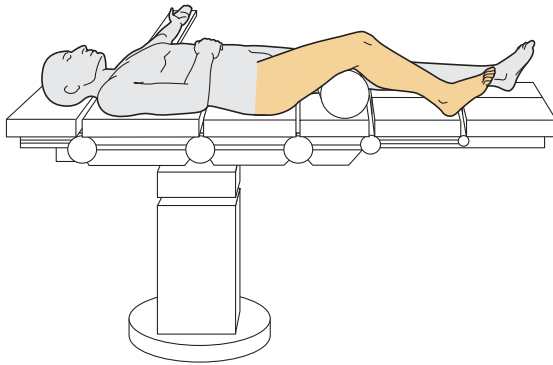
Fig 3.13.2-3a

Fig 3.13.2-3b

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6   Operating room set-up

- The ORP and surgeons stand on the lateral side of the affected limb.
- Position the image intensifier on the opposite side of the table medial to the fracture with the display screen in full view of the surgical team and the radiographer (Fig 3.13.2-4).
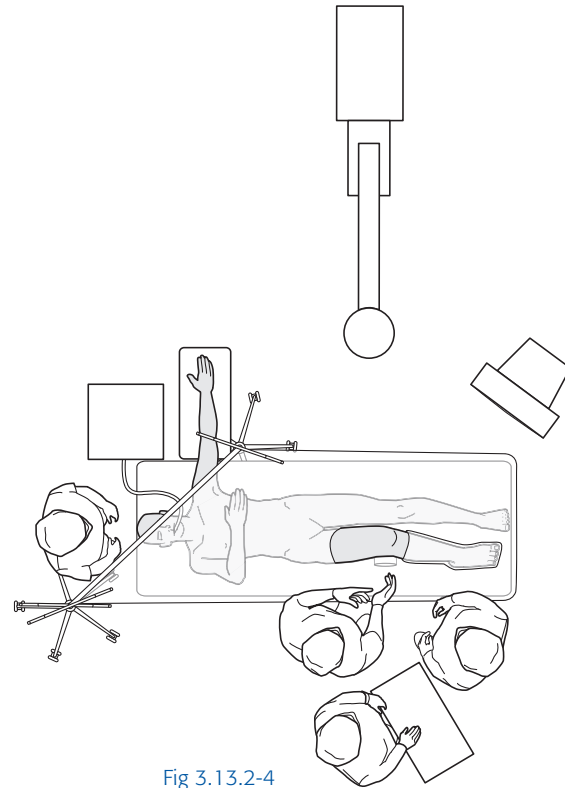
Fig 3.13.2-4

7 Instrumentation
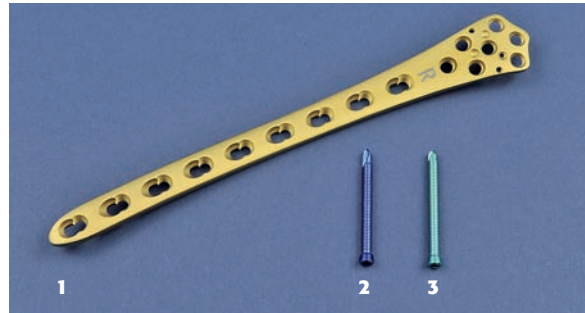
Fig 3.13.2-5a—Implants
1. Distal femoral locking compression plate (LCP-DF), 9 holes
2. Locking head screw 5.0 mm, self-drilling (less frequently used)
3. Locking head screw 5.0 mm, self-tapping

Fig 3.13.2-5b—Instruments for plate assembly
4. Insertion guide right, with lateral nuts
5. Drill sleeve
6. Fixation bolt
7. Stabilization bolt
8. Pin wrench
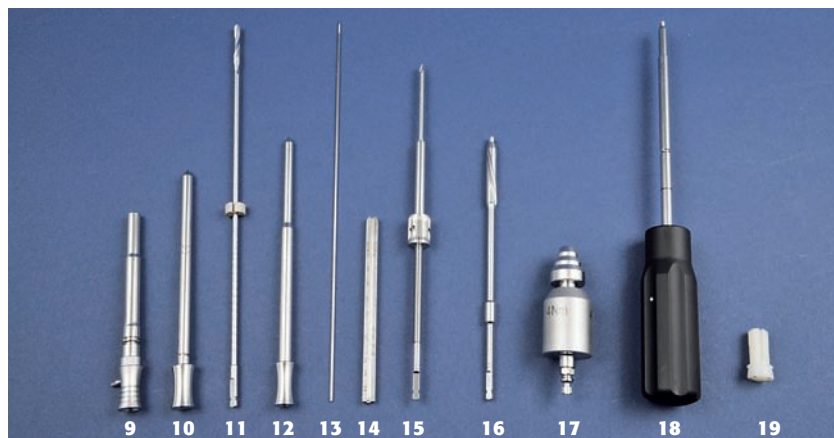
Fig 3.13.2-5c—Instruments for fracture fixation with LCP-DF 4.5/5.0
9. Drill sleeve
10. Trocar
11. Drill bit 4.3 mm
12. Centering sleeve for K-wires
13. K-wire 2.0 mm, 280 mm, with threaded tip (for preliminary fixation)
14. Measuring device for K-wires (to be used for self-drilling screws only)
15. Pulling device
16. Screwdriver shaft
17. Torque limiter 4 Nm
18. Screwdriver with torque limiter 4 Nm
19. White stopper

Author   Ian Harris

8   Procedure and technique—step-by-step

- Apply manual traction to the limb and assess the overall alignment using the image intensifier.
- Make an 8–10 cm longitudinal para patellar incision over the lateral femoral condyle.
- Deepen the incision through the lateral patellar retinaculum and joint capsule in the line of the skin incision to expose the lateral femoral condyle. Retracting the patella laterally or everting it allows visualization of the intraarticular element of the fracture.
- Reduce the articular fracture components anatomically under direct vision and fix them preliminarily with K-wires (Fig 3.13.2-6a).

- Simple fractures can be fixed with one or two cancellous lag screws lying outside the plate. Make a 3.2 mm drill hole, measure the depth, and tap the outer cortex. Insert an appropriate length 6.5 mm partially threaded cancellous bone screw and tighten it (Fig 3.13.2-6b). A washer may be used in poor-quality bone.
- More complex intraarticular fractures may require 3.5 or 4.5 mm cortex screws used as position screws, with the full length of the drill hole tapped before insertion.
- It is important that the screw heads do not lie in the area of the lateral condyle to be occupied by the plate.
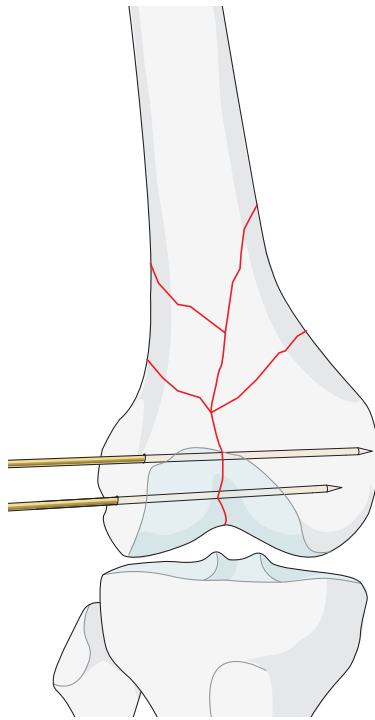
Fig 3.13.2-6a
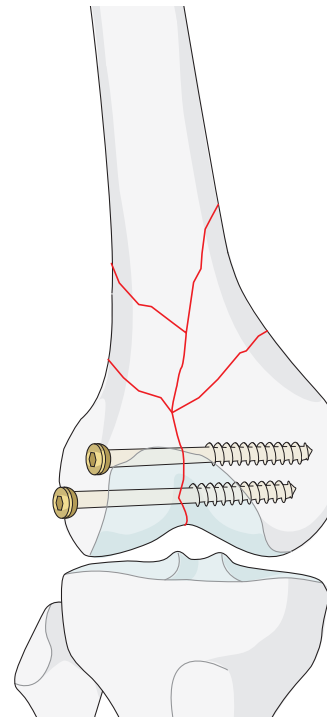
Fig 3.13.2-6b

- Remove the K-wires holding the intraarticular part of the fracture.
- Align the shaft of the femur to the reduced and fixed articular block by flexing the knee to release traction of the gastrocnemius muscles.
- Use K-wires for temporary fixation of the metaphyseal fracture. Alternatives include the application of a femoral distractor or external fixator to hold the femoral alignment and reduction while the plate is applied.
- Check the alignment and rotation of the articular block to the shaft of the femur with the image intensifier in both planes.
- Determine the length of the LCP-DF according to the level of the fracture and the extent of the comminution (minimum 9 holes).

- Assemble the main component and the radiolucent extension of the corresponding insertion guide (LCP-DF, left or right). Fix the insertion guide onto the distal part of the plate with the fixation bolt, which is passed through hole A and tightened with the pin wrench (Fig 3.13.2-6c).
- Introduce a stabilization bolt with drill sleeve into hole B in order to achieve a more stable fixation between the aiming arm and the plate (Fig 3.13.2-6d).
- Slide a tunneling instrument (scissors) along the lateral aspect of the femur to prepare for plate insertion.
- Insert the plate submuscularly, along the correctly reduced and aligned lateral border of the femoral shaft and approximate the distal end of the plate to the femoral condyle.
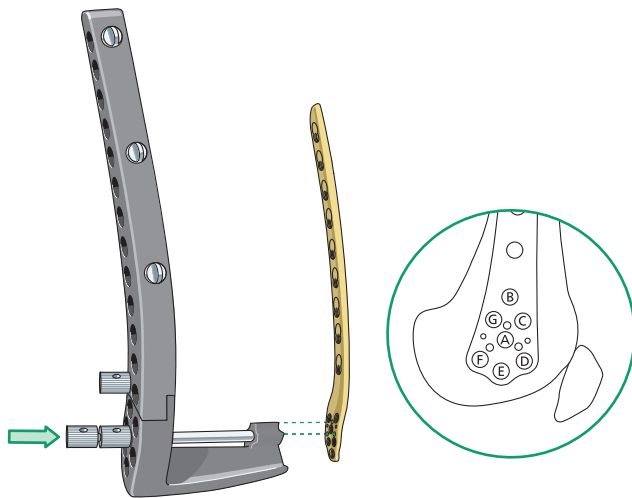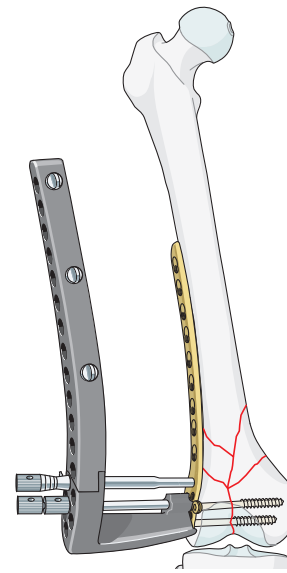

Fig 3.13.2-6c

Fig 3.13.2-6d

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- Insert the trocar and drill sleeve through the hole in the insertion guide that corresponds to the most proximal hole of the plate. Mark the skin and make an incision large enough to insert a finger and ensure the proximal end of the plate is aligned along the center of the femoral shaft.
- Correct alignment of the plate along the center of the femoral shaft is critical for the stability of the fixation of the plate to the bone. If the plate lies anteriorly or posteriorly the screws will only grip on one cortex and their hold in the bone will be compromised. It is difficult to accurately assess the position of the plate on the bone using a lateral C-arm image.
- Remove the trocar and insert a stabilization bolt through the drill sleeve and secure it in the proximal plate hole (Fig 3.13.2-6e).
- Insert a 2 mm threaded K-wire through the distal fixation bolt in the insertion guide to achieve temporary fixation of the condyle.
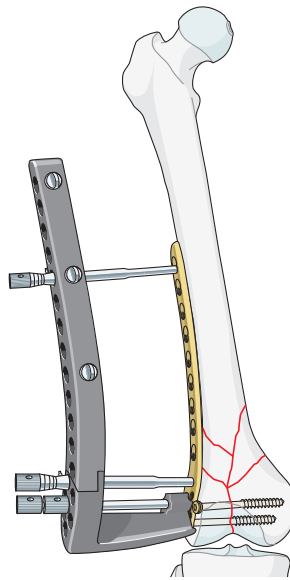
- Insert a second K-wire through the proximal stabilization bolt to fix the top end of the plate to the femoral shaft (if there are not enough drill sleeves and stabilization bolts, remove the pair from hole B to insert into the proximal hole) (Fig 3.13.2-6f).
- Confirm the alignment and position of the plate and K-wires in both AP and lateral views with the image intensifier.
- This "frame" construct facilitates further manipulation of the plate.
- If necessary, the plate can be manipulated to a position closer to the bone by temporary use of the pulling device in the middle portion of the plate. Make a stab incision; insert the self-drilling, self-tapping pulling device (without nut) into the bone, through a drill sleeve, with a power drill. Detach the drill and attach the nut. By tightening the nut against the drill sleeve, the bone is "pulled" toward the plate. Confirm reduction with the image intensifier.
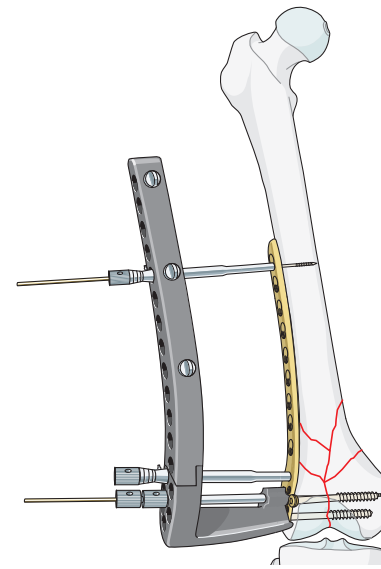

Fig 3.13.2-6e

Fig 3.13.2-6f

- Only insert a LHS once the reduction has been successfully completed and the plate is positioned correctly.
- Insert the first LHS distally through hole G in the distal block of the insertion guide.
- Pass the drill sleeve through the selected hole, insert, and screw the stabilization bolt into the threaded plate hole.
- Drill a hole using a 4.3 mm drill bit, measure the depth using the calibration on the drill bit (Fig 3.13.2-6g).
- Remove the stabilization bolt leaving the drill sleeve in place and insert the appropriate length self-tapping LHS 5.0 with the screwdriver shaft attached to a power drill, until the bulge in the shaft of the screwdriver reaches the top of the sleeve. This indicates the screw head is at the level of the plate. Then use the hand-held torque-limiting screwdriver for final screw tightening.
- Place a plastic stopper in the hole in the insertion guide to indicate that the hole has been filled with a screw.

- Insert a bicortical LHS proximally into the femoral shaft.
- Pass the drill sleeve with trocar through the appropriate hole in the proximal insertion guide and make a stab incision in the skin. Advance the sleeve down to the plate and replace the trocar with a stabilization bolt which is screwed into the plate hole. Drill the hole and insert the LHS as described above.
- Continue by inserting further LHS's into the distal articular block using holes B–F. A minimum of three LHS should be used distally, although more are advisable in poor-quality bone.
- With the length of the LHS in hole G established, the screw selection chart may be used to indicate subsequent screw lengths (Tab 3.13.2-1).
- Insert at least one additional bicortical LHS percutaneously in the proximal segment placing them far apart, and bridging the comminuted metaphyseal fracture zone.
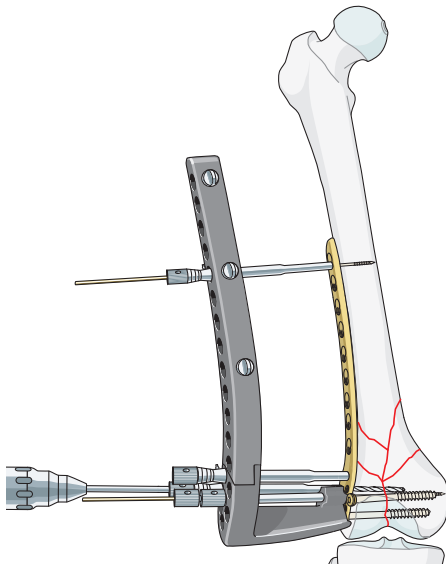

Fig 3.13.2-6g

Width of condyles	60–80 mm	81–87 mm	88–95 mm	96–110 mm
Screw selection		Screw length, mm		
Hole A	65	75	75	85
Hole B	40	40	55	65
Hole C	40	55	65	75
Hole D	55	65	65	75
Hole E	65	75	75	75
Hole F	65	75	75	85
Hole G	55	65	75	85

Tab 3.13.2-1—Screw selection chart.

Author   Ian Harris

- Remove the K-wires. These may be replaced with more LHS if required. They should not be removed until at least two LHS have been placed each side of the fracture (Fig 3.13.2-6h).
- If the pulling device has been used it may now be removed and if required an additional LHS inserted in its place.
- Use the pin wrench to loosen the fixation bolts and remove the insertion guide from the plate.
- Bone grafting is usually not required provided the comminuted fracture area has not been exposed or manipulated.
- Check the screw length, implant position, and fracture reduction in both planes and save copies with the image intensifier.
- Close the wound.
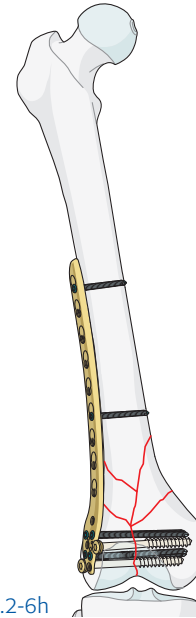
Fig 3.13.2-6h

9   Specific perioperative care

- Be careful with pressure areas, particularly in the elderly.
- Ensure that imaging access is adequate before disinfecting.
- Maintain sterility as the image intensifier is moved from AP to lateral position.

- Avoid excessive deformity at the fracture site during preparation and draping.

10 Specific postoperative care

- Perform x-ray documentation by saving image intensifier views or take formal postoperative x-rays.
- Splinting of the limb should not be necessary unless fixation is poor, or if other injuries are present that require splinting.
- Encourage early movement of the knee, preferably by continuous passive motion.

- Partial weight bearing (10–15 kg) may be started within 2 weeks in compliant patients, while full weight bearing should be delayed until 8–12 weeks after surgery depending on the fracture healing.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Be careful to identify the different drill sleeves, bolts, and their function.
- Have three or even four drill sleeves available (used with trocar, stabilization bolt for drilling, K-wire fixation, and the pulling device).

- Be prepared for application of different types of screws.
- Consider small-fragment 3.5 mm cortex screws for fixation of articular fragments.
- Consider femoral distractor or external fixator set for reduction.
- Remember cooling when inserting self-drilling locking head screws.
- Discard threaded K-wires.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Understand the normal anatomy of the distal femur and the features of the implants.
- Be mindful of the fracture reduction throughout the procedure by regularly checking alignment on both AP and lateral views, and checking rotation radiographically and clinically, particularly before inserting screws.
- Be aware that with locking plates the fracture must be reduced and aligned before the plate application. Lag screws may not be applied secondarily through a locked plate if locking head screws have already been inserted.

- Use the torque-limiting screwdriver for the locking screws. If power is used to insert the screws, the final few turns should always be done by hand with the torque limiter to prevent the screws jamming in the plate.
- Ensure a long enough plate is selected to provide adequate fixation of the proximal fragment and especially if the plate is used for bridging a comminuted fracture zone.
- When locking plates are used to bridge a comminuted fracture, longer plates are applied than if conventional plates are used. Generally, about half the screw holes are left unfilled. Detailed preoperative planning is mandatory when using these techniques to ensure optimum stabilization of the fracture.

Author   Ian Harris

3.13.3 Intraarticular distal femoral fracture (33-C2): stabilization with dynamic compression screw (DCS)

Surgical management

- Open reduction and stabilization with dynamic compression screw (DCS)

Alternative implants

- Less invasive stabilization system (LISS)
- LCP-distal femur (LCP-DF)
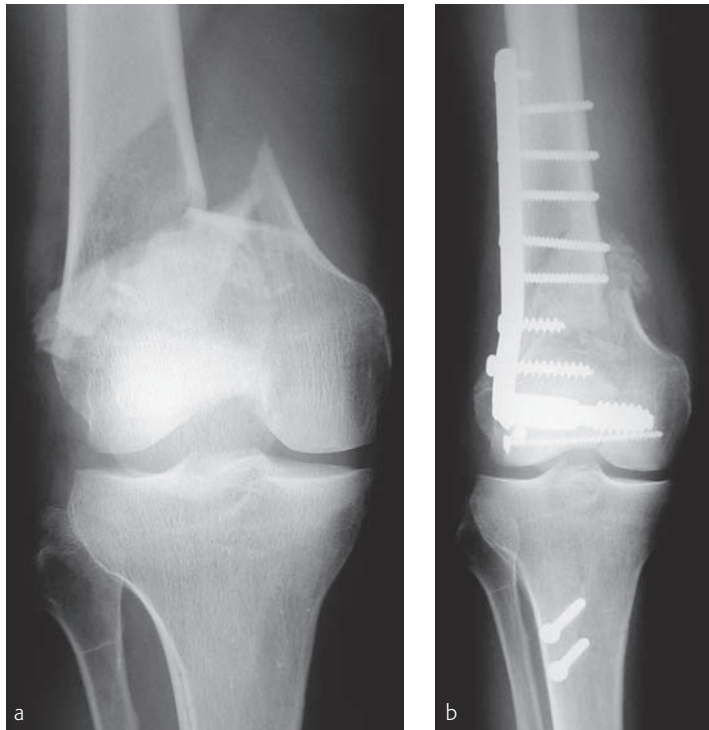- 95° condylar blade plate for adults

1   Introduction

- The intraarticular part of these fractures requires anatomical reduction and fixation with one- or two-plate independent lag screws. A simple metaphyseal component of the fracture can be reduced and rigidly fixed. More complex fractures are best managed with the plate applied as a bridging plate.
- A DCS is only recommended if at least 4 cm of the distal femur and the medial cortex of the medial femoral condyle are intact to provide support for the implant.
- The DCS is particularly useful if locking head screws and plates are not available.
- As nonlocking screws are used, the fixation is dependent on compression between the bone fragments, and between the plate and the bone. This may be compromised in patients with osteoporosis.
- Knowledge of the normal orientation of the distal femur to the shaft (5°–9° of valgus) is necessary.

Fig 3.13.3-1a–b
a   Preoperative x-ray: intraarticular distal femoral fracture.
b   Postoperative x-ray: stabilization with lag screws and dynamic compression screw (DCS).

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- DCS implant selection of plates and screws
- DHS/DCS instrument set
- Basic instrument and screw set 4.5/6.5
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

Author   Ian Harris

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Position the patient supine on a radiolucent operating table.
- Use a roll to provide knee flexion which relaxes the pull of the gastrocnemius muscles (which force the fracture into extension) and allows lateral imaging of the distal femur (Fig 3.13.3-2a).

- Ensure adequate imaging of the femur from the shaft to the knee in the AP and lateral views (Fig 3.13.3-2b-c).
- A tourniquet may be applied (inflate only when needed) if it does not obstruct the placement of the plate. If in doubt, apply a sterile tourniquet after draping.
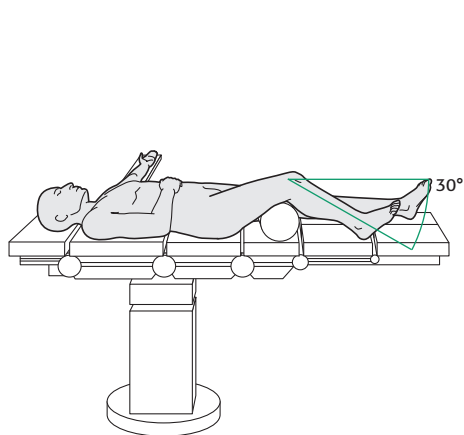
Fig 3.13.3-2a
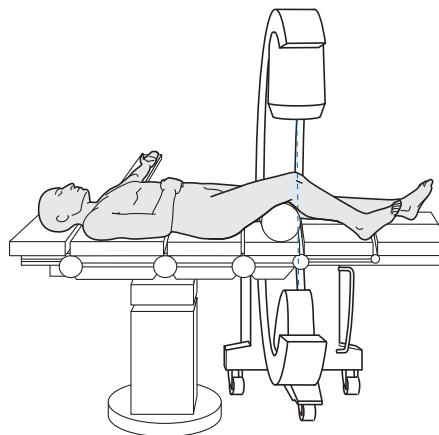
Fig 3.13.3-2b
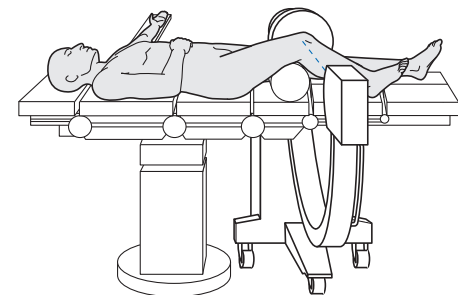
Fig 3.13.3-2c

5 Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the whole leg from the hip including the foot with the appropriate antiseptic (Fig 3.13.3-3a).
- Drape the limb with a single-use U-drape or extremity drape. A stockinette covers the foot and lower leg and is fixed with a tape.

- Drape the leg to allow it to be freely moved (Fig 3.13.3-3b).
- Flex the knee slightly over a roll of padding.
- Drape the image intensifier.
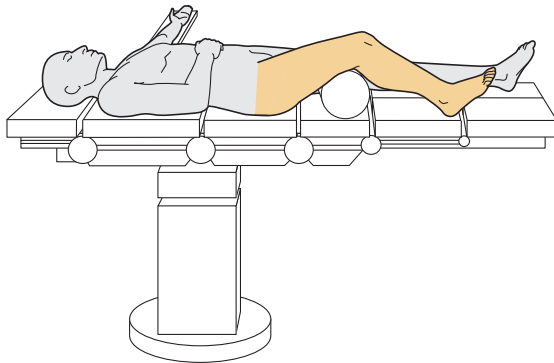
Fig 3.13.3-3a
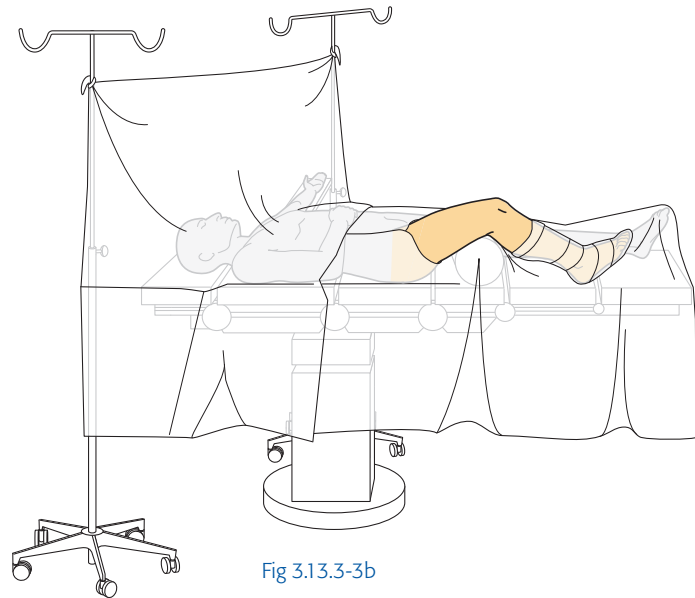
Fig 3.13.3-3b

Author   Ian Harris

6   Operating room set-up

- The ORP and surgeons stand on the side of the affected limb.
- Position the image intensifier on the opposite side of the table medial to the fracture with the display screen in full view of the surgical team and the radiographer (Fig 3.13.3-4).
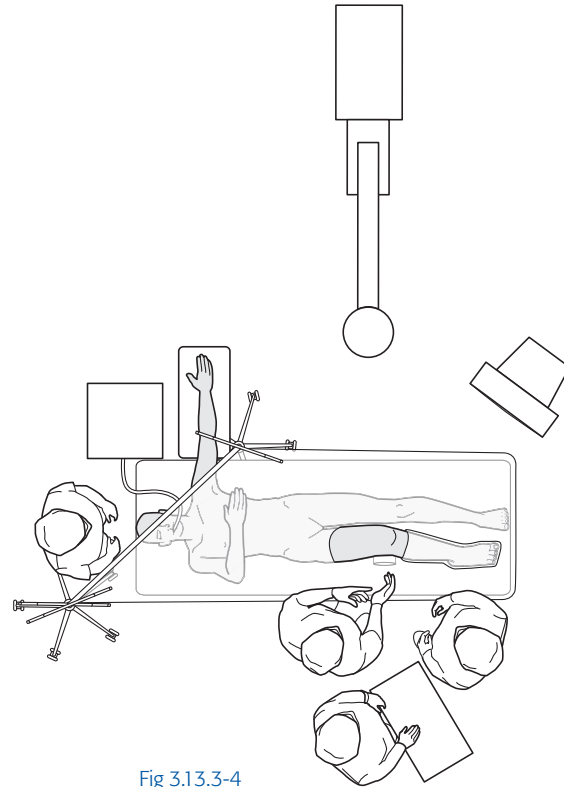
Fig 3.13.3-4

7 Instrumentation

Fig 3.13.3-5a—Implants
1. DCS plate
2. DCS screw
3. Cortex screw 4.5 mm
4. DCS compression screw

Fig 3.13.3-5b—Instruments for insertion of DCS
5. Guide wire 2.5 mm, 230 mm, threaded
6. DCS angled guide
7. DHS/DCS T-handle
8. DHS/DCS measuring device
9. DCS triple reamer (drill bit 8.0 mm, DCS reamer and nut)
10. DHS/DCS quick coupling
11. DHS/DCS tap
12. DHS/DCS centering sleeve
13. DHS/DCS insertion wrench with connecting screw
14. DHS/DCS impactor
15. Hammer

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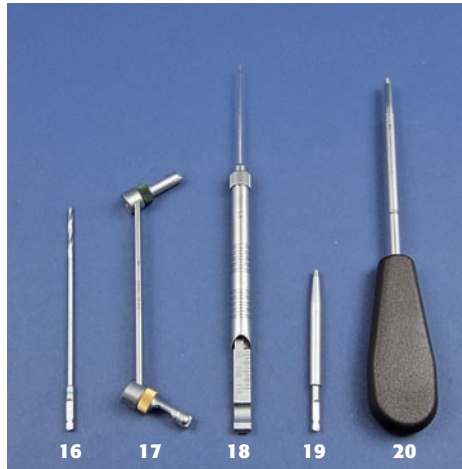
Fig 3.13.3-5c—Instruments for plate fixation
16. Drill bit 3.2 mm
17. DCP drill sleeve 4.5
18. Depth gauge
19. Screwdriver shaft
20. Screwdriver
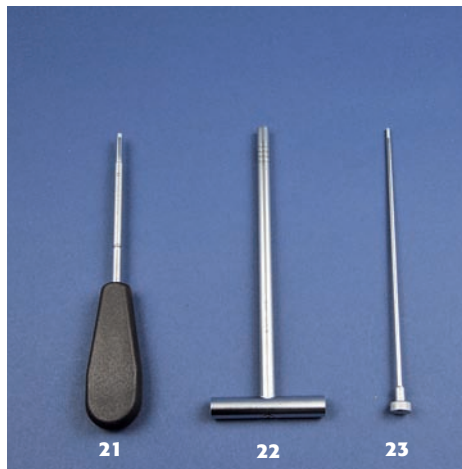
Fig 3.13.3-5d—Instruments for implant removal
21. Screwdriver
22. DHS/DCS wrench for removal
23. DHS/DCS connecting screw, long

8   Procedure and technique—step-by-step

- Make a lateral longitudinal incision from the level of the knee joint to above the fracture proximally on the lateral aspect of the thigh.
- Divide the fascia lata in the line of the skin incision and expose the lateral surface of the femoral condyle, the fracture, and the femoral shaft by lifting the vastus lateralis off the lateral intermuscular septum.
- Divide the lateral patella retinaculum and knee joint capsule to expose the knee joint laterally. Retract the patella medially to provide exposure of the intraarticular component of the fracture.
- Reduce the intraarticular fragments anatomically and provide temporary fixation with bone reduction clamps or K-wires (Fig 3.13.3-6a).

- Mark the entry point for the DCS screw and position of the distal part of the plate using the DCS angled guide with T-handle as a template. The insertion point should be approximately 2 cm proximal to the knee joint, in line with the shaft of the femur, at the junction between the anterior one third and posterior two thirds of the lateral condyle.
- Use one or two partially threaded 6.5 mm cancellous bone screws for fixation of the intraarticular component of the fracture. Place the screws anteriorly and interiorly so as not to interfere with the placement of the DCS screw and plate which has been marked.
- Drill the screw hole with a 3.2 mm drill bit, measure the depth, and tap the outer cortex of the bone. Insert an appropriate length 6.5 mm partially threaded cancellous bone screw and tighten it. Insert a second screw using the same technique (Fig 3.13.3-6b-c).
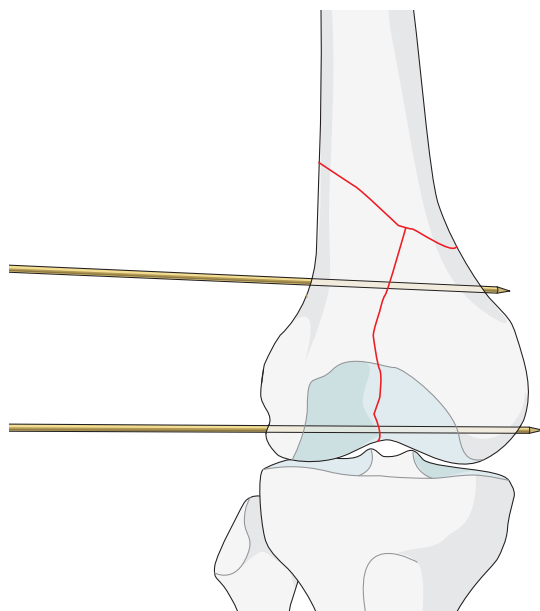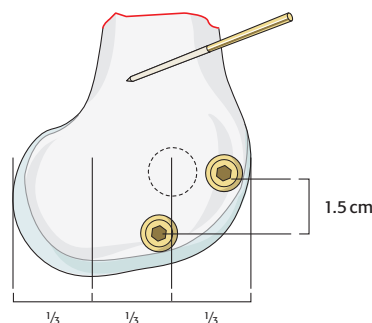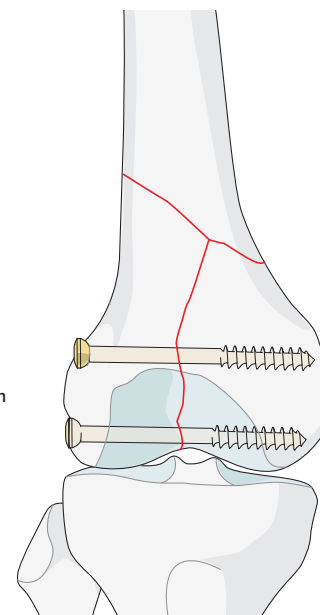

Fig 3.13.3-6a

Fig 3.13.3-6b

Fig 3.13.3-6c

Author   Ian Harris

- In poor-quality bone these cancellous bone screws should be used with washers.
- In a small patient the amount of space for the lag screws and the DCS can be limited and careful planning is required before placing any screws. Use of 4.0 mm partially threaded cancellous bone screws with washes may help.
- Reduce the metaphyseal component of the fracture using direct manipulation, and temporarily hold the reduction using reduction forceps or K-wires.
- If possible, fix the metaphyseal fracture with interfragmentary 4.5 mm cortical lag screws.

- Use three K-wires for the correct orientation of the DCS screw: the first 2.0 mm K-wire (A) marks the plane of the knee joint; the second (B) one is placed anteriorly over the two femoral condyles and marks the plane of the patellofemoral joint.
- Insert the third (C)—the 2.5 mm DCS guide wire—using the angled guide with T-handle, into the condyles at the site of the plate entry point running parallel to the two other wires. Insert it until the tip is touching the cortex of the medial condyle (Fig 3.13.3-6d-e).
- Check the position and depth of the guide wire with the image intensifier.
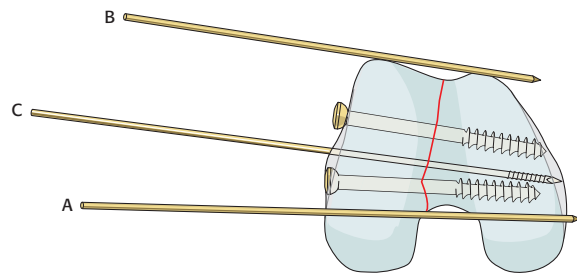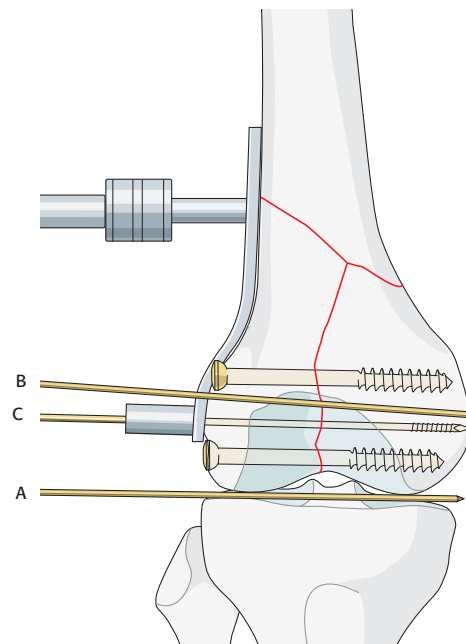

Fig 3.13.3-6d

Fig 3.13.3-6e

- Slide the direct measuring device over the 2.5 mm DCS guide wire to determine the DCS screw length (Fig 3.13.3-6f).
- Set the DCS triple reamer 10 mm shorter than the length measured.
- Attach the DCS reamer to the power drill using the DHS quick coupling and ream the hole (Fig 3.13.3-6g).
- The guide wire may be accidentally removed with the reamer: if this occurs, replace it by using the centering sleeve and an inverted DCS screw. Check the position on the image intensifier.
- If the bone is hard, tap the thread for the DCS screw using the tap and the centering sleeve. Tap until the selected depth is read off in the small window of the centering sleeve.

One-step technique for plate and screw insertion:
- Assemble plate, screw, and sleeve.
- Insert the coupling screw into the wrench and slide the appropriate plate onto the wrench, then connect the DCS screw with the coupling screw and add the centering sleeve.
- Insert the DCS screw and plate over the guide wire using the centering sleeve until the zero mark is level with the lateral cortex (Fig 3.13.3-6h).
- The handle of the insertion wrench must finish in a position parallel with the femoral shaft.
- Check the screw length and position with the image intensifier in both planes.
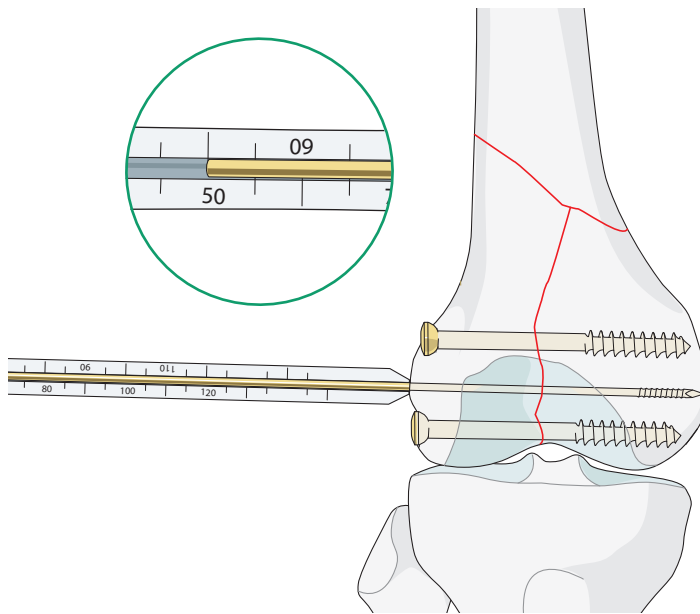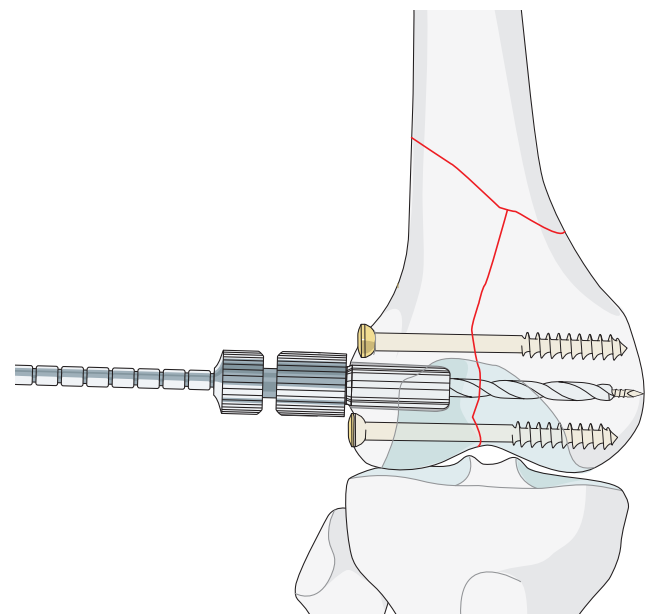
Fig 3.13.3-6f

Fig 3.13.3-6g

Author   Ian Harris

- Slide the DCS plate over the DCS screw so that the plate lies on the lateral cortex of the femur. If the plate does not sit perfectly you may need to bevel the superior part of the bone of the condyle using a chisel.
- If the fracture configuration allows, a DCS compression screw may be used to apply further compression to the intercondylar component of the fracture. It is removed after usage.
- If the metaphyseal component of the fracture is proximal enough, reinforce the distal fixation of the DCS plate using a cancellous bone screw through one of the distal (round) holes. Make a 3.2 mm drill hole, measure the depth, tap the outer cortex, and insert an appropriate length 6.5 mm partially threaded cancellous bone screw.

- Fix the plate to the shaft of the femur proximally with 4.5 mm bicortical cortex screws. Drill a 3.2 mm hole, measure the depth, tap the hole, and insert a 4.5 mm cortex screw of appropriate length (Fig 3.13.3-6i).
- Perform imaging to check implant position and fracture reduction throughout the procedure.
- Save final images for documentation.
- Close the wound.

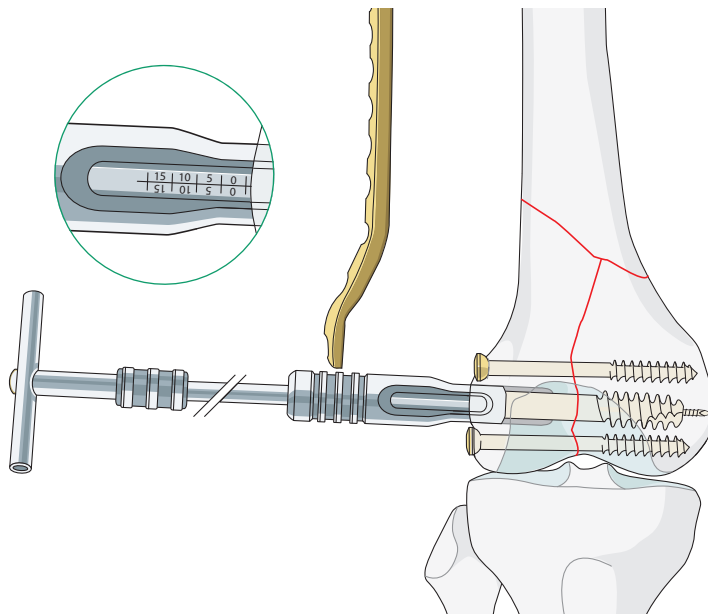Further information is available on AO Teaching video 20155: Dynamic Condylar Screw.
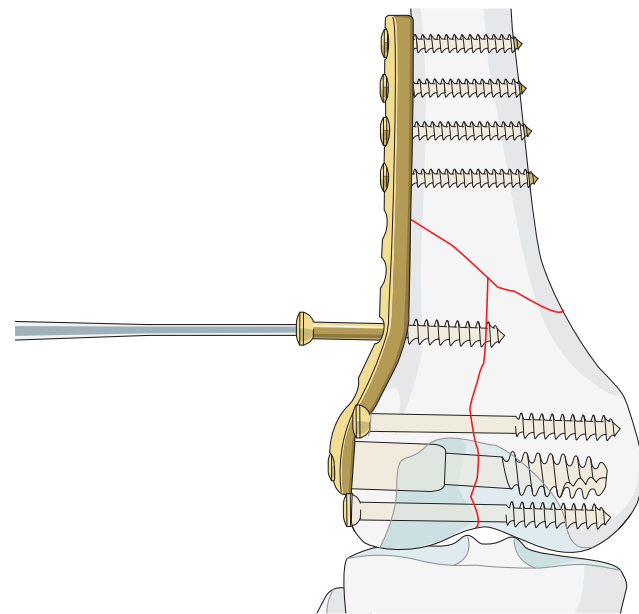

Fig 3.13.3-6h

Fig 3.13.3-6i

Alternative variation of using DCS as a bridging plate:
- The DCS may also be used as a bridging plate if the metaphyseal component of the fracture is multifragmentary. The steps are similar but the metaphyseal fracture is not exposed.
- Fix the intraarticular components of the fracture as described above and insert the DCS screw into the condyles.
- Reduce the metaphyseal fracture by closed indirect maneuvers.
- Insert the correct length plate submuscularly with the barrel facing away from the lateral condyle, and slide the plate up the shaft of the femur.

- Rotate the plate through 180º and engage the barrel over the DCS screw shaft. This will cause considerable temporary distortion of the soft tissues while the plate is fitted over the DCS screw.
- Make a separate more proximal incision to expose the shaft of the femur and the proximal end of the plate.
- Check the reduction and, if satisfactory, fix the proximal shaft with at least three cortex screws, and reinforce the fixation distally with cancellous bone screws if possible. Before inserting the first screw ensures that the plate is in the center of the femoral shaft.

9 Specific perioperative care

- Be careful with pressure areas, particularly in the elderly.
- Ensure that imaging access is adequate before creation of the sterile field.

- Maintain sterility as the image intensifier is moved from AP to lateral position.
- Avoid excessive deformity at the fracture site during preparation and draping.

10 Specific postoperative care

- Perform x-ray documentation by saving the image intensifier films or performing formal postoperative x-rays.
- Splinting of the limb should not be necessary unless fixation is poor, or if other injuries are present that require splinting.

- Immediate movement of the knee is encouraged, preferably with continuous passive motion.
- Weight bearing is limited for 6–12 weeks.

Author   Ian Harris

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Note that DCS instruments are included in the DHS instrument set. The instruments exclusively used for the DCS are the DCS angled guide and the DCS triple reamer. The other instruments are the same as for DHS insertion.
- Make sure the short barrel triple reamer (marked DCS) is used.

- Note that different sized K-wires are used for preliminary fracture fixation and orientation.
- Ensure a new 2.5 mm threaded guide wire is used for the DCS implantation.
- Confirm the agreed reamer setting with the surgeon.
- Flush the cannulated triple reamer carefully.
- Ensure there is no guide wire left in the reamer.
- Discard the guide wire after use.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Understand the normal anatomy of the distal femur and the features of the implants.
- Decide on the mode of use of the plate at the metaphyseal fracture (compression, protection, or bridging) as part of the preoperative plan.
- Minimize the soft-tissue disruption as much as possible. Make sure that there is adequate exposure to allow reduction and fixation, especially for the intraarticular element of the fracture.

- Ensure that the interfragmentary screws used to fix the intra-articular component are placed so that they do not interfere with placement of the DCS implant.
- Ensure a long enough plate is selected to provide adequate fixation of the proximal fragment.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.14   Patella fractures

Author   Wa'el Taha

3.14   Patella fractures

Case

- Transverse articular patellar fracture

Introduction

- According to the Müller AO/OTA Classification the patella is bone number 34. Fractures of the patella are divided into three groups:
  - type 34-A: extraarticular or extensor mechanism disruption
  - type 34-B: partial articular, vertical fractures
  - type 34-C: complete articular with disrupted extensor mechanism
- The patella is a flat triangular sesamoid bone located within the quadriceps femoris tendon. The quadriceps muscle inserts into the superior, medial, and lateral aspect of the bone. The patellar tendon originates from the inferior apex and inserts into the tibial tuberosity on the upper and anterior aspect of the tibia.
- The patella has a cranial (superior) base and an extraarticular caudal (inferior) apex.
- The articular surface of the patella has the thickest layer of cartilage in the body reflecting the huge loads put through the joint. It forms a joint with the distal femoral trochlea and intracondylar area.

- Patellar fractures are most commonly caused by direct trauma to the knee. Typical signs are swelling, tenderness, and limited or absent function of the extensor mechanism.
- Extraarticular fractures involve the distal apex of the patella. The extensor mechanism is disrupted as a result of loss of continuity between the apex of patella with the attached patellar tendon and the main body of the patella. These injuries can be managed with lag screws that are reinforced by a cerclage wire between the patella and the tibial tuberosity. In patients where these fractures are severely comminuted or where the bone is severely osteoporotic, partial patellectomy with repair of the extensor mechanism is advised.
- Partial articular fractures are usually vertical fracture of the patella which only involves part of the articular surface. If displacement is minimal or there is no displacement, treatment can be conservative. If displaced, they can be fixed with a transverse lag screw or a cerclage wire.
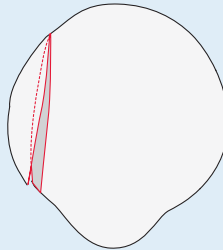
Müller AO/OTA Classification—patella fracture

| 34-A | 34-B1 | 34-B2 |
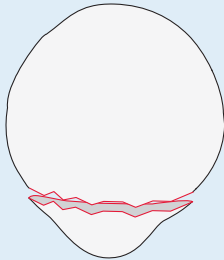
34-A   extraarticular
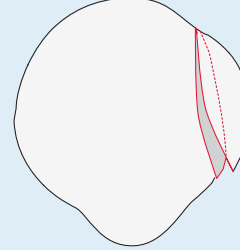34-A1   extraarticular, avulsion

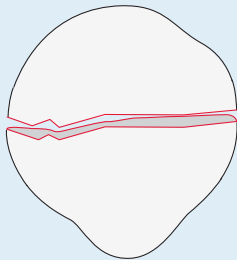**34-B   partial articular, vertical**
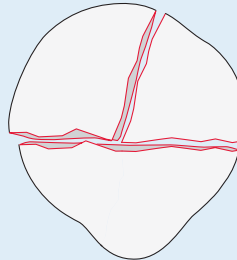34-B1   lateral
34-B2   medial

| 34-C1 | 34-C2 | 34-C3 |

34-C   complete articular, nonvertical
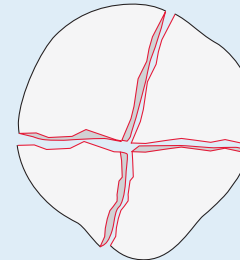34-C1   transverse
34-C2   transverse plus second fragment
34-C3   articular, comminuted

3.14.1   Transverse patella fracture (34-C1): stabilization with tension band wiring

Surgical management

- Stabilization with tension band wiring—1.25 mm cerclage wire and 1.8 or 2.0 mm K-wires

Alternative implant

- Tension band wiring with 3.5 or 4.0 mm lag screws

1   Introduction

- Complete articular fractures are usually transverse fractures which involve the articular surface. If the two fragments are big enough and the articular surface can be restored, then they can be fixed with K-wires and tension band wiring.

- Tension band wiring can also be used in fractures with four or more pieces. Supplementary screw and/or K-wire fixation is also needed.
- Total patellectomy is rarely indicated even in highly comminuted fractures. The results of total patellectomy are poor.
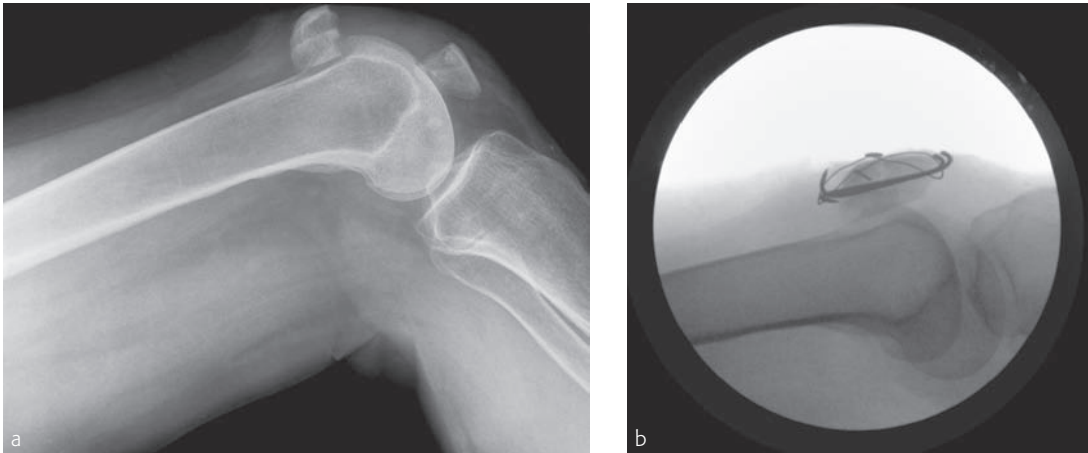
Fig 3.14-1a–b
a   Preoperative x-ray: transverse patella fracture.
b   Postoperative x-ray: stabilization with two K-wires and tension band wire.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- K-wire selection 1.8 mm (size used depends on individual anatomy)
- Cerclage wire 1.0 or 1.25 mm
- Wire instrument set
- Curved wire guide

- Reduction forceps, large
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Attachment for K-wire insertion

Equipment:
- Radiolucent table
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)
- Sandbag/bump

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4 Patient and x-ray positioning

- The patient is anesthetized and placed in the supine position on a radiolucent table.
- Apply a correctly sized tourniquet to the femur with adequate padding.
- Place a sandbag or bump under the ipsilateral buttock to internally rotate the limb and put a roll under the knee to flex it to about 30º (Fig 3.14-2).
- Be careful of soft tissues and skin pressure points.
- Adjust the operating table to an appropriate height.
- Place the image intensifier on the opposite side of the injured limb and check AP lateral views.
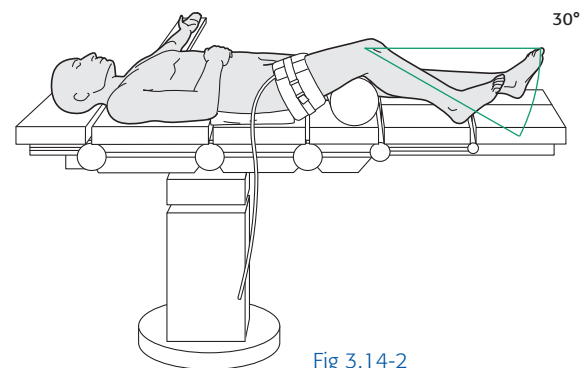

30°

Fig 3.14-2

Author   Wa'el Taha

5   Skin disinfecting and draping

- Position the patient and disinfect the leg from the mid femur downward including the foot (Fig 3.14-3a).
- A single-use U-drape or extremity drape may be used. A stockinette covers the foot and lower leg and is fixed with an adhesive tape.
- Drape the leg to allow it to be moved freely (Fig 3.14-3b).
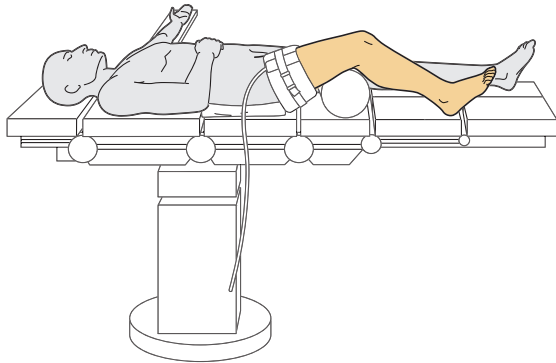- Flex the knee slightly over a roll.
- Drape the C-arm.

Fig 3.14-3a

Fig 3.14-3b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- The first assistant stands on the opposite side.
- The image intensifier is placed on the opposite side of the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.14-4).
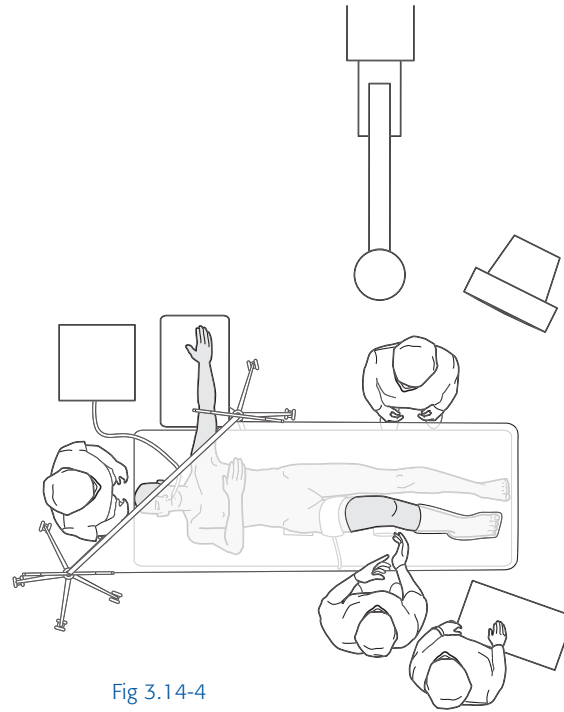

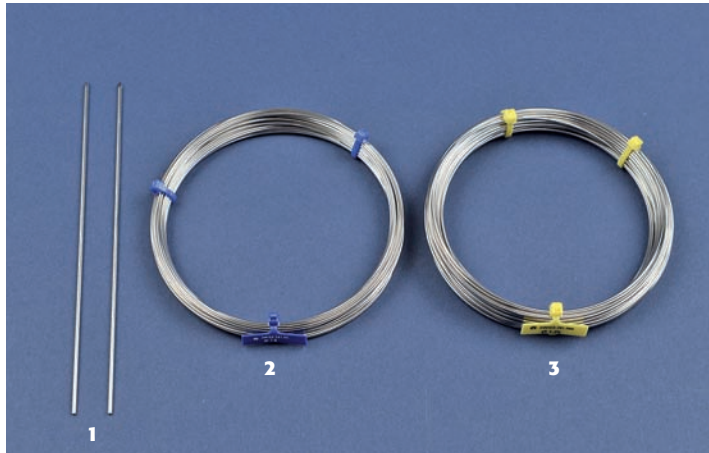Fig 3.14-4

7   Instrumentation

Fig 3.14-5a   Implants
1.   K-wires 1.8 mm
2.   Coil with cerclage wire 1.0 mm
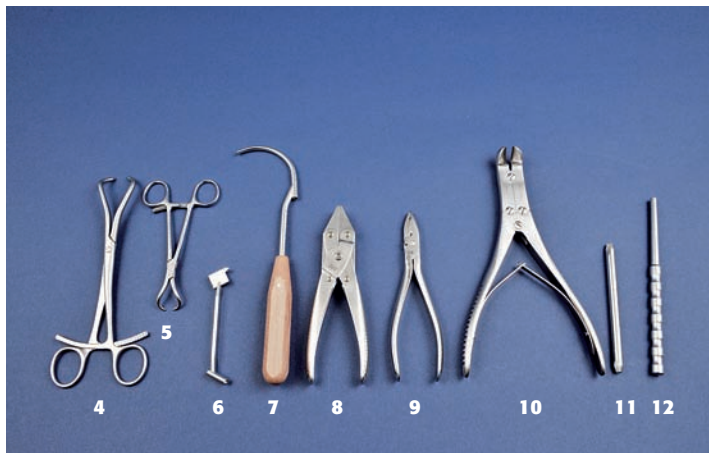3.   Coil with cerclage wire 1.25 mm

Fig 3.14-5b   Instruments for fracture fixation with tension band wire
4.   Reduction forceps with points, large
5.   Reduction forceps with points, medium
6.   Triple drill guide
7.   Curved guide wire
8.   Parallel pliers, flat nosed
9.   Wire bending pliers
10. Wire cutter, large
11. Bending iron for K-wires
12. Impactor for K-wires

8 Procedure and technique—step-by-step

- Incision—make a midline longitudinal incision. Although cosmetically attractive transverse incisions are not recommended. Many of these patients may require secondary surgery, such as total knee replacement many years after sustaining a fracture. If possible, the incision used for fracture fixation should not interfere with the incisions needed for future surgery.
- Open the deep fascia in line with the skin incision. Expose the extensor apparatus.
- The knee joint is visible through the distracted fragments of the patella.
- Irrigate the knee joint and fracture to clear any debris.
- Fragments are best reduced in hyperextension. The bulk of the quadriceps muscle can get trapped proximal to an inflated tourniquet which can make reduction difficult. Deflating the tourniquet or not using one avoids this problem.

Fig 3.14-6a

- Reduce the fracture and hold it reduced with the pointed reduction forceps.
- Check the reduction by palpating the articular surface of the patella. This can easily be done by inserting a finger through the defect in the patella retinaculum. The quality of reduction of the articular surface is the most important prognostic indicator for the success of the procedure. The quality of reduction cannot be assessed radiologically or by inspection of the anterior surface of the bone.
- Two techniques are available for K-wire insertion.
- Using the outside-in technique insert two parallel K-wires from superior to inferior in an axial direction (Fig 3.14-6a).
- Using the outside-in technique insert two K-wires through the unreduced fracture surface, passing the wires superiorly until the wires are 5–10 cm beyond the superior surface of the patella. Then pull the wires out until their tips are just protruding at the fracture surface of the proximal fragment. Using the wires as joysticks manipulate the fracture fragments to obtain a reduction. Check the accuracy of reduction by palpation and then pass the wires inferiorly through the distal fracture fragment to emerge at the lower border of the patella.
- For either technique the ideal position of the K-wires is 5 mm from the anterior surface of the bone.
- Insert a curved wire passer as close as possible to the upper pole of the patella through one side of the quadriceps tendon and behind the protruding K-wires and out the other side. If a suitable wire passer is not available, use a short segment of drain tubing.
- Push a sufficiently long (eg, 30 cm) 1.25 or 1.0 mm cerclage wire manually into the lumen of the guide wire (or tubing) and pull it through, leaving the cerclage wire in place (Fig 3.14-6b).
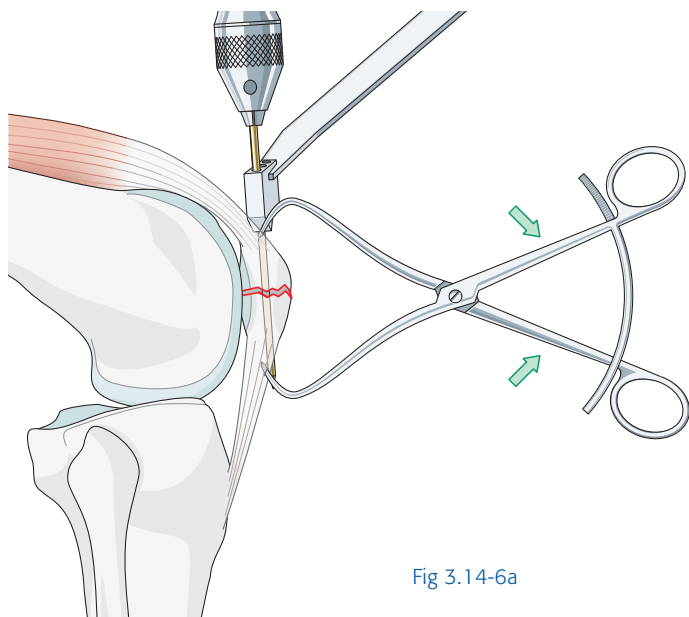
Author   Wa'el Taha

- Create a figure-of-eight with the cerclage wire, looping it beneath the distal ends of the K-wires deep to the patella tendon.
- Bring the ends of the wire together on one side of the patella and create a loop of wire on the other side.
- Twist and tighten the cerclage wire equally on each side with the knee in extension using pliers. Ensure the twisted wire lies to the sides of the figure-of-eight so it does not protrude under the skin.
- Check reduction with the image intensifier.
- Shorten both K-wires proximally with a wire cutter, bend them over the cerclage wire with pliers, and punch them into the patella to prevent skin irritation and loosening.
- To make subsequent removal easier, trim but do not bend the distal K-wire ends.
- Cut twisted ends of cerclage wire short and turn the sharp ends with pliers against the bone to prevent soft-tissue damage or protrusion (Fig 3.14-6c).
- Repair the torn medial and lateral retinaculae.
- Take and save copies of final x-rays.
- Deflate tourniquet (if it was used) and achieve hemostasis.
- Close the wound.
- Flex the knee to 90º under direct vision and ensure that the fixation is adequate to allow early active movement of the knee joint.

Further information is available on AO Teaching video 30097: Transverse Fracture of the Patella—Tension Band Wiring.

Fig 3.14-6b

Fig 3.14-6c
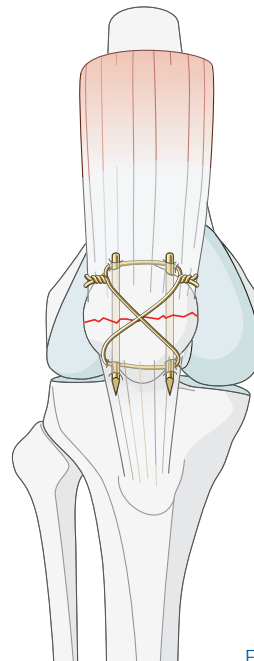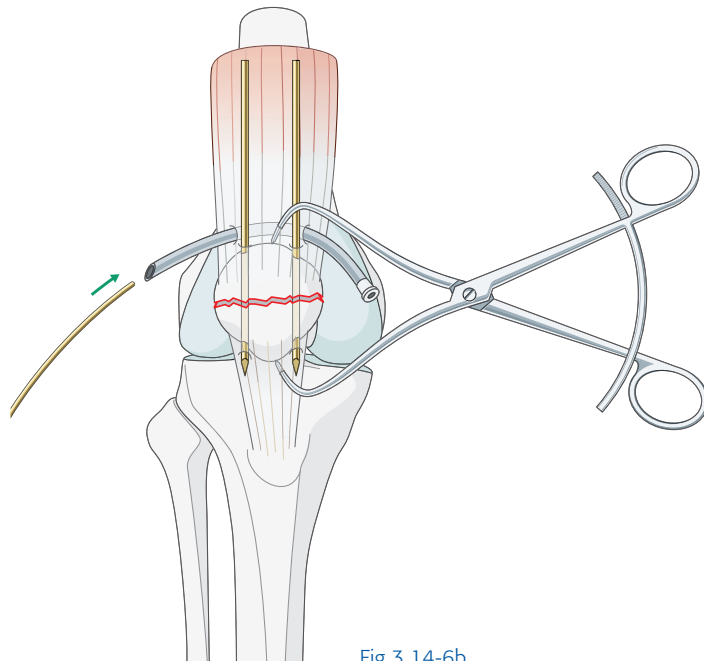
9 Specific perioperative care

- Confirm the patient is secured on the operating table with a safety belt and/or side supports.
- Pay attention to pressure areas.
- Maintain sterility as the image intensifier is rotated around the surgical field.
- Pay attention when trimming wires.

10 Specific postoperative care

- X-rays should be taken postoperatively to check and document reduction and position of implant unless adequate images were taken from the image intensifier.
- Casting is not necessary with tension band wiring.
- Start early active motion of the knee immediately. Active motion is beneficial to articular cartilage healing.
- A knee brace may be helpful until quadriceps control is regained.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of K-wires, cerclage wires, and instruments are available.
- Remember to have the curved wire passer (or drain tube) and large reduction forceps available.
- Have two pairs of pliers available to ensure simultaneous tightening of the tension band wire, thus producing more balanced pressure at the fracture site.
- Provide extra large reduction forceps (optional).
- Discard used wires and be cautious with cut pieces.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Fracture reduction is achieved by extending the knee.
- Check the reduction of the patella fracture carefully by palpation of the articular surface and with image intensification.
- Position entry points of the two K-wires axial as far apart as possible to enhance fixation stability, but ensure they are parallel.
- Make sure all sharp edges left after shortening the wires are well buried to avoid skin irritation and wound infection.
- Beware of flying pieces of metal when cutting wires.
- Inform the patient preoperatively that wires are likely to need removal once the fracture has healed.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.15   Proximal tibial fractures

Implants and surgical technique

- 7.0 mm cannulated screws
- LCP-L buttress plate 4.5/5.0, left leg
- LCP proximal lateral tibia plate (PLT) 3.5 and LCP proximal medial tibia plate (PMT) 3.5

Cases

- Partial articular split fracture of lateral tibial plateau (41-B1)
- Partial articular split depression fracture of lateral tibial plateau (41-B3)
- Complete articular fracture—articular complex, metaphyseal multifragmentary (41-C3)

Introduction

- The Müller AO/OTA Classification divides proximal tibial fractures into three main groups:
  - type 41-A: extraarticular fractures
  - type 41-B: partial articular fractures which consist of a pure split fracture (41-B1), pure depression fracture (41-B2), or split-depression fracture (41-B3)
  - type 41-C: complete articular fracture with separation of all articular fragments from the metaphysis. These are further subdivided into articular simple, metaphyseal simple (41-C1), articular simple, metaphyseal multifragmentary (41-C2), or articular and metaphyseal multifragmentary (41-C3)
- Injuries to the tibial plateau can occur as the result of a medially directed force causing a valgus deformity at the knee, a laterally directed force causing a varus deformity, an axial compression force, or a combination of both axial and lateral loading. Fracture pattern is determined by the direction of force, the energy involved, and the strength of the tibial bone on one side and that of the collateral ligaments on the other side.
- High-energy injuries even in the absence of open fractures will result in significant soft-tissue damage. Because the tibial plateau is subcutaneous, high-energy injuries traumatize the skin. Early surgery in this type of injury frequently results in wound breakdown and skin necrosis.

- Fractures of the tibial plateau may be associated with injuries to collateral or cruciate ligaments as well as the menisci, lateral peroneal nerve, or popliteal vessels. The neurovascular structures may also be injured during internal fixation.
- The knee joint is a major weight-bearing joint. Failure to ensure that tibial plateau fractures heal with both restoration of the articular surface and restoration of the axial alignment of the lower limb may result not only in joint stiffness and instability but also in posttraumatic degenerative change.
- Finally failure to reconstruct significant ligament damage resulting in joint instability will also predispose the patient to posttraumatic osteoarthrosis.

Absolute indications for surgery include:
- Open fracture
- Fractures with associated compartment syndrome or acute neurovascular injuries
- Fractures with articular displacement more than 5 mm (although in young or active patients more than 2 mm may be unacceptable)
- Axial malalignment
- Knee joint instability

Müller AO/OTA Classification—tibia/fibula: proximal segment

| 41-A1 | 41-A2 | 41-A3 | 41-B1 | 41-B2 | 41-B3 | 41-C1 | 41-C2 | 41-C3 |

41-A   extraarticular fracture
41-A1   avulsion
41-A2   metaphyseal simple
41-A3   metaphyseal multifragmentary

41-B   partial articular fracture
41-B1   pure split
41-B2   pure depression
41-B3   split-depression

41-C   complete articular fracture
41-C1   articular simple, metaphyseal simple
41-C2   articular simple, metaphyseal multi-
         fragmentary
41-C3   articular multifragmentary

Author   Peter Campbell

3.15.1   Partial articular split fracture of lateral tibial plateau (41-B1): stabilization with 7.0 mm cannulated screws

Surgical management

- Stabilization with 7.0 mm cannulated screws

Alternative implants/technique

- Cannulated screws 6.5/7.3 or 4.5 mm
- T or L buttress plate 4.5
- LCP-T or -L buttress plate 4.5
- LCP (PLT) 3.5
- Arthroscopic-assisted surgery

1   Introduction
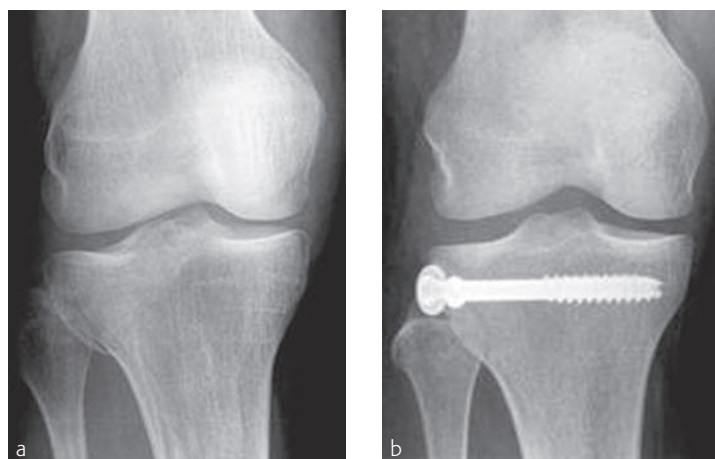
Fig 3.15.1-1a–b
a   Preoperative x-ray: split fracture of tibial plateau.
b   Postoperative x-ray: stabilization with two cannulated 7.0 mm screws.

- Split wedge fractures of the lateral tibial plateau without significant depression of the articular surface tend to occur in younger patients in whom the stronger, denser cancellous bone is better able to resist compression. This type of fracture results from a combination of forces, directed both axially and medially, resulting in a valgus deformity—classically being hit on the outer side of the knee as a sporting or motor vehicle injury.
- It is possible for the lateral meniscus to be trapped within the fracture line; therefore, even in peripheral, minimally displaced fractures an examination under anesthetic and arthroscopy to assess stability of the fracture and meniscal integrity should be considered.
- Washers should be used under the head of the screws to prevent them sinking into the cancellous bone when tightened.
- If there is any concern over the stability of the fixation or the quality of the bone, an additional buttress plate is required.
- Although the open method of fixing this fracture is described here, where displacement is minimal and arthroscopic assessment of the joint available, it is sometimes possible to reduce the fracture and insert the screws percutaneously.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (open/closed)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- 7.0 mm cannulated screw set
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Laminar spreaders
- Femoral distractor or external fixator as a reduction aid

Equipment:
- Radiolucent operating table
- Table and positioning accessories to assist supine position and individual position of both legs
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (rarely needs to be inflated)

Additional equipment that may be required:
- Arthroscopic camera, instruments, and monitor stack for arthroscopic-assisted cases

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- If regional anesthesia is used, appropriate measures must be in place to monitor compartment pressures in the lower leg muscle compartment. Compartment syndromes can occur, and if the patient is still under regional anesthesia he/she will not be able to complain of pain which is the earliest and most important symptom of a compartment syndrome.
- If a spinal anesthetic is used, the surgeon needs to be confident that the procedure can be performed within the time available before anesthetic wears off. In practice this is about 90 minutes, although subject to considerable individual variation.

Author   Peter Campbell

4   Patient and x-ray positioning

- The patient is placed supine on the operating table.
- Flexion of the knee up to 90º is required during surgery. This improves visualization of the joint surface and permits the iliotibial band to slip posteriorly from the lateral condyle. Obtain knee flexion either by "breaking" the table at the level of the knee and hanging the lower leg off the end of the table, or using a large bolster under the patient's thigh (Fig 3.15.1-2).
- Place the opposite leg supine on the operating table or into an abducted position with the hip and knee flexed to allow easier access for the image intensifier.
- Ensure that soft tissues, skin pressure points, and the subcutaneous nerves (ulnar nerve at the elbows and peroneal nerve of the opposite knee) are well protected.
- Adjust the operating table to the appropriate height and place the image intensifier on the opposite side of the injury, approaching the knee from the medial aspect.
- Ensure adequate posterior and lateral x-ray views can be taken.
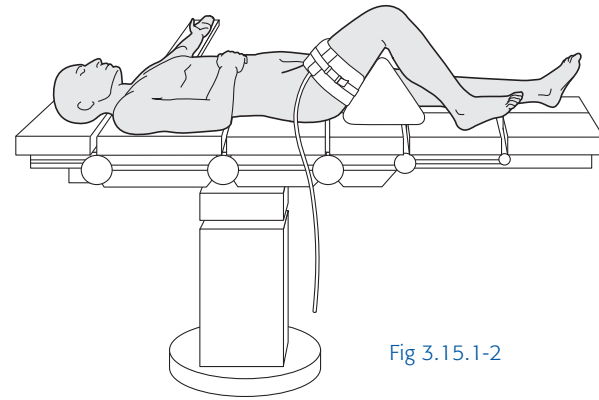
Fig 3.15.1-2

5 Skin disinfecting and draping

- Apply a thigh tourniquet, which is inflated only if needed.
- Maintain light manual traction on the limb during preparation.
- Disinfect the exposed area from mid thigh to the foot with the appropriate antiseptic (Fig 3.15.1-3a).

- Drape the limb with a single-use U-drape or extremity drape. A stockinette covers the foot and lower leg and is fixed with a tape (Fig 3.15.1-3b).
- Drape the image intensifier.
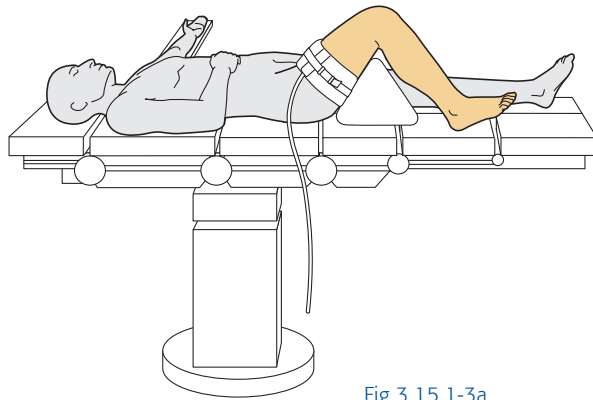
Fig 3.15.1-3a
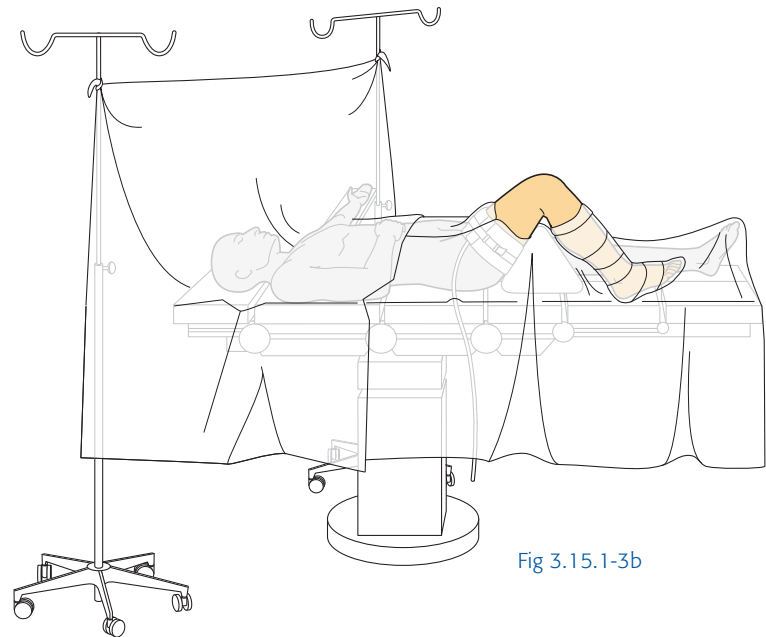
Fig 3.15.1-3b

Author Peter Campbell

6 Operating room set-up

- The surgeon and the assistant stand (or sit) on the side of the injury.
- The ORP stands next to the surgeon.
- Position the image intensifier on the opposite side of the injury with the screen in full view of the surgical team and the radiographer (Fig 3.15.1-4).
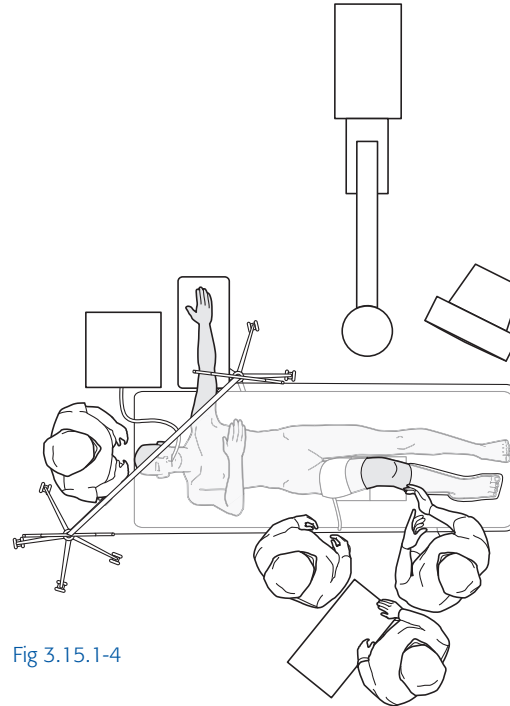
Fig 3.15.1-4

7 Instrumentation
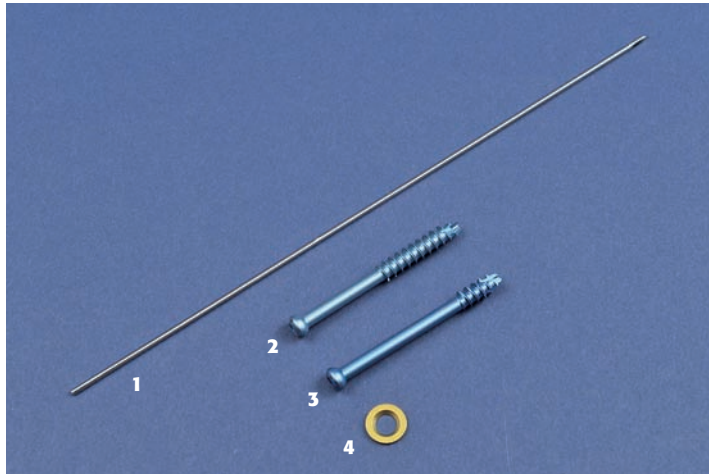
Fig 3.15.1-5a   Implants
1.   K-wire 2.0 mm, 230 mm
2.   Cannulated screw 7.0 mm, thread 32 mm
3.   Cannulated screw 7.0 mm, thread 16 mm
4.   Washer
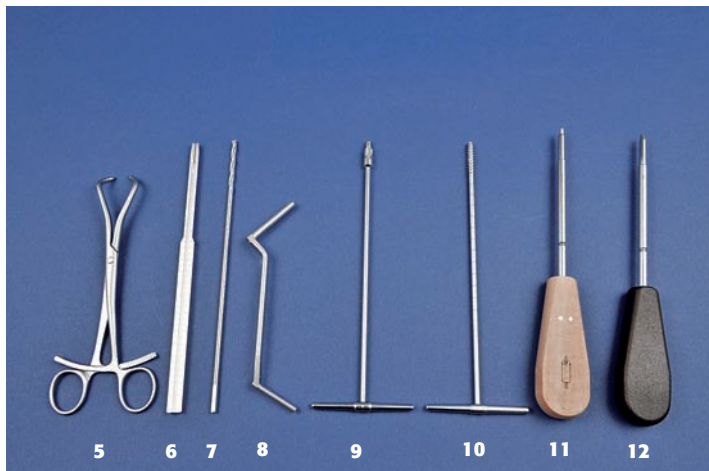
Fig 3.15.1-5b   Instruments for fracture fixation with cannulated screws 7.0 mm
5.   Reduction forceps with points
      Note: reduction forceps with points, extra large (not in picture)
6.   Direct measuring device
7.   Drill bit 4.5/2.1 mm
8.   Double drill sleeve 4.5/3.2 mm
9.   Cannulated countersink 7.0 mm
10.   Cannulated tap 7.0 mm
11.   Cannulated screwdriver
12.   Screwdriver

Author   Peter Campbell

8   Procedure and technique—step-by-step

- Make a 6–8 cm longitudinal lateral parapatellar incision on the anterolateral aspect of the knee. Begin 4–6 cm above the joint line and extend the incision distally over the proximal tibia. The length of the distal extension will depend on the anatomy of the fracture and the technique used for fixation.
- Proximally deepen the approach in the line of the skin incision dividing the lateral patellar retinaculum and joint capsule. Distally expose the fracture line with minimum soft-tissue dissection.
- Incise the capsule horizontally just below the level of the meniscus to provide direct visualization of the articular surface. Preserve a sufficient cuff of soft tissue to allow repair of the meniscus during closure.
- Expose the fracture line and remove hematoma and debris with a wash out and a curette.

- Reduce the fracture and hold it provisionally with a large-pointed reduction forceps (Fig 3.15.1-6a). Make a small stab incision on the medial side of the tibia to allow the medial point of the reduction forceps to grip on the bone.
- Using a drill sleeve insert a 2.0 mm guide wire with threaded tip approximately 1 cm below the lateral joint line. Position this K-wire to ensure that it does not interfere with the insertion of the other screws used for definitive fixation. Note that the lateral tibial plateau is concave and higher than the convex medial tibial plateau. Take care that the guide wires are inserted up to, but not protruding through, the medial cortex.
- Insert a second guide wire parallel to the first just below the level of the joint surface (Fig 3.15.1-6b). A third guide wire may be inserted at the apex of the fragment, distally if required. Check the position of the guide wires with the image intensifier.
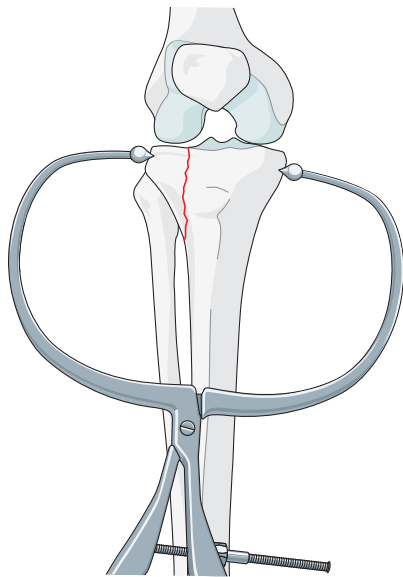
Fig 3.15.1-6a
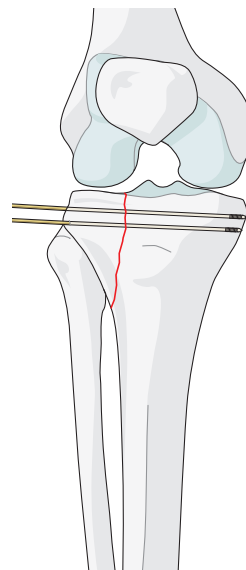
Fig 3.15.1-6b
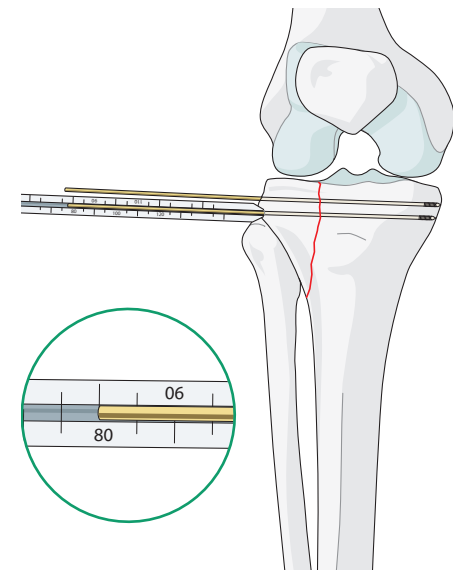
Fig 3.15.1-6c

- Determine the length of the screws with the direct measuring device once the wires are correctly positioned (Fig 3.15.1-6c).
- If necessary make separate stab incisions to insert the wires/screws. This is better than carrying out extensive soft-tissue stripping to reach the appropriate point through the initial incision.
- Use the 4.5 mm cannulated drill bit over the first guide wire to broach the lateral cortex (Fig 3.15.1-6d). The screws are self-drilling and self-tapping but in very good-quality bone it may be necessary to advance the drill bit to within 1 cm of the tip of the guide wire.

- Insert the selected screw with a washer (Fig 3.15.1-6e). In most fracture patterns, screws with 32 mm threads are appropriate. Make sure that the entire screw thread passes beyond the fracture line allowing the screw to compress the fracture.
- Use washers to avoid countersinking of screw heads into cortex.
- Repeat the procedure for additional screws (Fig 3.15.1-6f).
- Take a final x-ray. Check in both planes and print or save hard copy images taken from the image intensifier.
- Close the wound, ensuring the meniscal attachment is repaired.
- Check the stability of the knee to valgus stress. Most associated medial collateral ligament injuries can be treated nonoperatively but such injuries may require bracing during rehabilitation.

Fig 3.15.1-6d
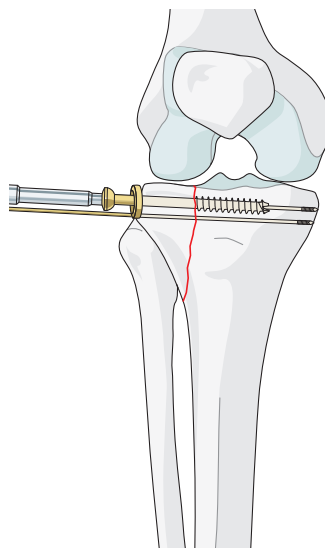
Fig 3.15.1-6e

Fig 3.15.1-6f

Author   Peter Campbell
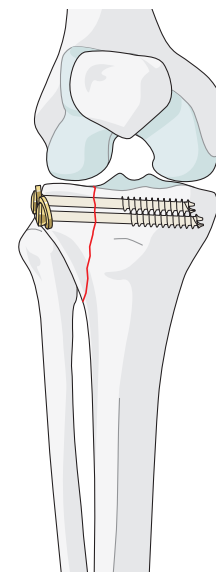
9   Specific perioperative care

- Exercise care with pressure areas, particularly where subcutaneous nerves are at risk (both elbows and contralateral knee).
- Ensure tourniquet is correctly applied and inflated to correct pressure, only if needed.
- Maintain sterility as the image intensifier is rotated around the surgical field.

10   Specific postoperative care

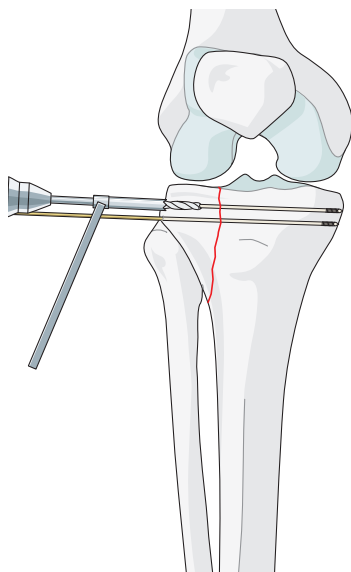- Take postoperative x-rays to check and document reduction and position of implants unless adequate images were taken from the image intensifier.
- Fixation should allow early active mobilization that should start as soon as possible postoperatively.
- A continuous passive motion machine may be used to assist with early movement until postoperative discomfort settles.
- Mobilize patients with partial weight bearing on crutches with or preferably without a hinged knee brace or cast. Bracing is most useful if there are associated ligament injuries.
- Start progressive weight bearing when there is clinical and radiological evidence of uneventful healing. Full weight bearing can normally begin after 6–8 weeks.

11   ORP—key points

- Cross-check that details of patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Have extra large reduction forceps available.
- Ensure that new guide wires of the correct size are used each time. Always have additional correct guide wires available.
- Check screw length and select correct thread length.
- Offer the surgeon a conventional screwdriver for final tightening of the cannulated screws.
- Check that the guide wire is not jammed in the cannulated drill bit after use.
- Flush and preclean all cannulated instruments carefully.
- Discard guide wires after use.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of patient, side, marking, and site of surgery are correct.
- Draw up an appropriate plan and tactic for the operation before starting.
- Ensure satisfactory patient set-up.
- Ensure clear x-rays can be obtained in both planes.
- Ensure careful handling of soft tissues and fracture fragments to maintain blood supply and avoid devitalization.
- Take care to preserve a rim of soft tissue, when detaching the meniscus during the approach, to allow adequate repair.
- Position guide wires to take into account subsequent wires and screws. Avoid penetration of medial cortex with guide wire or screw.

- Check that the guide wire does not become jammed within the drill bit and is pushed out through the medial cortex as the drill is advanced.
- Make sure that the screw threads only engage beyond the fracture line to provide interfragmentary compression.
- Use washers with screws.
- Be careful when using an arthroscope, that there is no escape of fluid from the knee into the calf which could cause compartment syndrome.

Author   Peter Campbell

3.15.2   Partial articular split depression fracture of lateral tibial plateau (41-B3): stabilization with LCP-L buttress plate 4.5/5.0, left leg

Surgical management

- Stabilization with LCP-L buttress plate 4.5/5.0, left leg

Alternative implants/technique

- T or L buttress plate 4.5
- LCP-T buttress plate 4.5/5.0
- LCP proximal lateral tibia plate (PLT) 3.5
- Arthroscopic-assisted surgery

1   Introduction

- Split depression fractures usually occur when the cancellous bone cannot withstand the compressive load sustained during the combined axial and valgus deformation.
- These fractures usually require bone graft or bone substitute. The best site for an autogenous graft is the ipsilateral iliac crest.

- The principles of treatment involve elevation of the articular fragments with restoration of the joint congruity and buttress plating of the lateral proximal tibial cortex.
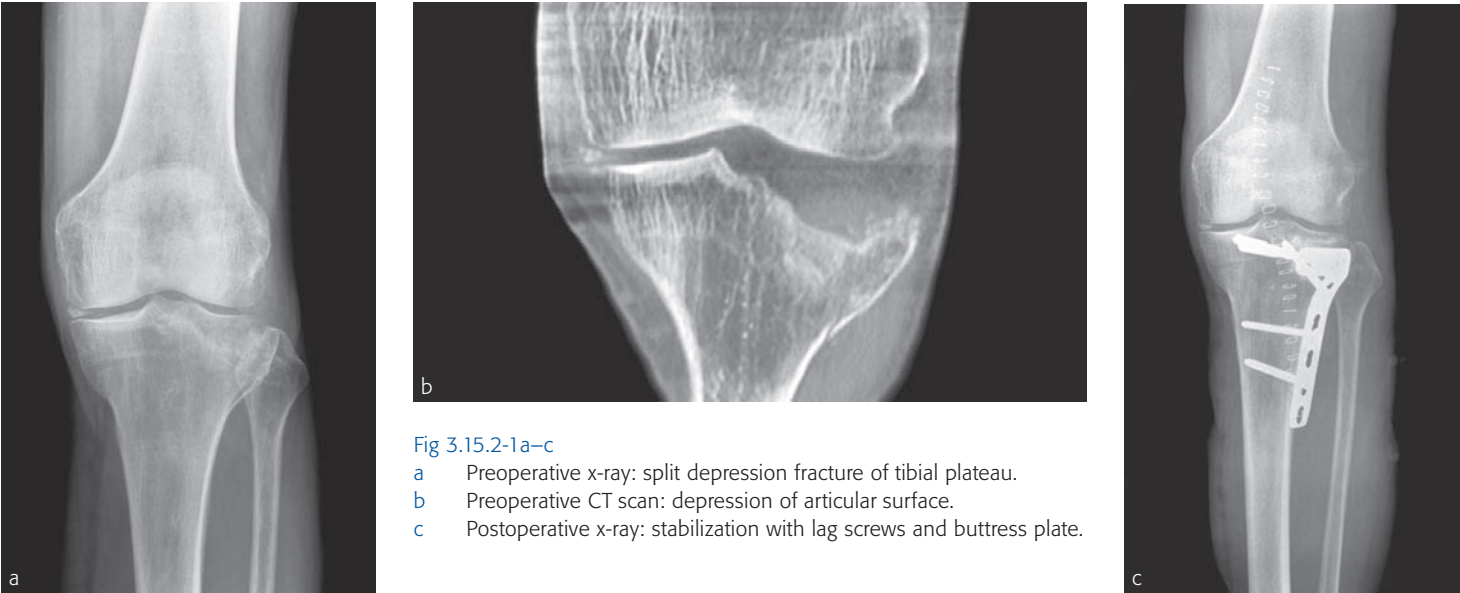
Fig 3.15.2-1a–c
a   Preoperative x-ray: split depression fracture of tibial plateau.
b   Preoperative CT scan: depression of articular surface.
c   Postoperative x-ray: stabilization with lag screws and buttress plate.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open/closed)
- Implant to be used (the plate comes in right and left versions)
- Patient positioning
- Bone graft harvesting
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Basic instrument and screw set 4.5/6.5
- LCP-L buttress plate 4.5/5.0, left leg
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Additional instruments that may be required:
- 7.0 mm cannulated screw set
- Small fragment instrument and screw set 3.5/4.0 mm
- Laminar spreaders
- Femoral distracter or external fixator as a reduction aid
- Osteotomes and curettes for bone graft harvesting

Equipment:
- Radiolucent operating table
- Table and positioning accessories to assist supine position and individual position of both legs
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (rarely needs to be inflated)

Author   Peter Campbell

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- If regional anesthesia is used, appropriate measures must be in place to monitor compartment pressures in the lower leg muscle compartments. Compartment syndromes can occur, and if the patient is still under regional anesthesia he/she cannot complain of pain which is the earliest and most important symptom of a compartment syndrome.

- If a spinal anesthetic is used, the surgeon needs to be confident that the procedure can be performed within the time available before anesthesia wears off. In practice this is about 90 minutes, although subject to considerable individual variation.

4   Patient and x-ray positioning

- Position the patient supine on the operating table.
- Flexion of the knee up to 90º is required during surgery. This improves visualization of the joint surface and permits the iliotibial band to slip posteriorly from the lateral condyle. Obtain knee flexion either by "breaking" the table at the level of the knee and hanging the lower leg off the end of the table, or using a large bolster under the patient's thigh (Fig 3.15.2-2).
- Place the opposite leg supine on the operating table or into an abducted position with the hip and knee flexed to allow easier access for the image intensifier.
- Care must be taken to ensure that soft tissues, skin pressure points, and the subcutaneous nerves (ulnar nerve at the elbows and peroneal nerve of the opposite knee) are well protected.
- Adjust the operating table to the appropriate height and place the image intensifier on the opposite side of the injury, approaching the knee from the medial aspect.
- Ensure that adequate posterior and lateral views can be taken.
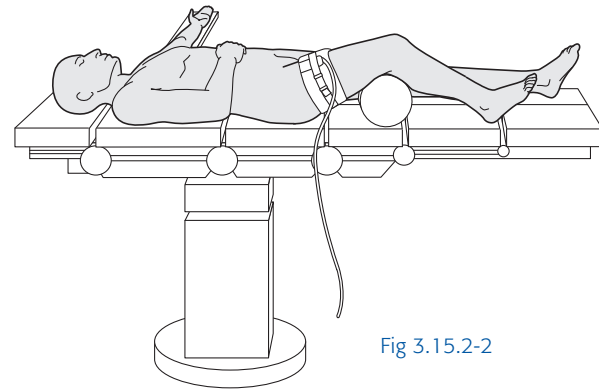
Fig 3.15.2-2

5 Skin disinfecting and draping

- Apply a tourniquet to the thigh, which is inflated only if needed.
- Maintain light manual traction on the limb during preparation.
- Disinfect the exposed area including the iliac crest and the foot with the appropriate antiseptic (Fig 3.15.2-3a).

- Drape the limb with a single-use U-drape or extremity drape (Fig 3.15.2-3b).
- Drape the iliac crest separately.
- Cover the foot and lower leg with a stockinette and fix it with a tape.
- Drape the image intensifier.
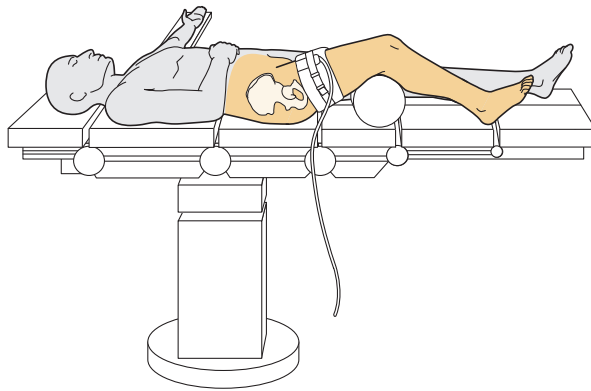
Fig 3.15.2-3a

Fig 3.15.2-3b

Author   Peter Campbell

6   Operating room set-up

- The surgeon and the assistant stand (or sit) on the side of the injury.
- The ORP stands next to the surgeon.
- Position the image intensifier on the opposite side of the injury and place the display screen in full view of the surgical team and the radiographer (Fig 3.15.2-4).
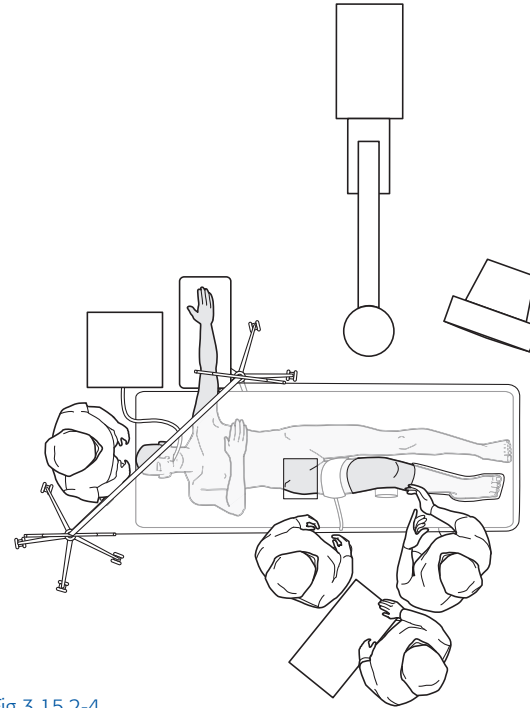
Fig 3.15.2-4

7 Instrumentation

Fig 3.15.2-5a   Implants
1.   LCP-L buttress plate 4.5/5.0, left leg
2.   Locking head screw 5.0 mm, self-tapping
3.   Cancellous bone screw 6.5 mm, thread 32 mm
4.   Cancellous bone screw 6.5 mm, thread 16 mm
5.   Cortex screw 4.5 mm

Fig 3.15.2-5b   Instruments for plate fixation with conventional and LHS screws

6. Drill bit 3.2 mm	14. T-handle
7. Drill bit 4.3 mm	15. Screwdriver shaft
8. Universal drill sleeve 4.5/3.2	16. Torque limiter attachment, 4 Nm
9. Double drill sleeve 6.5/3.2	
10. LCP drill sleeve 4.3 mm	17. Handle for torque limiter
11. Depth gauge	18. Torque indicating screwdriver, 4 Nm
12. Tap 4.5 mm for cortex screws	
13. Tap 6.5 mm for cancellous bone screws	19. Screwdriver

Fig 3.15.2-5c   Instruments for reduction and contouring
20.   Bending press
21.   Reduction forceps with points, large
22.   Bending iron (two)

Author   Peter Campbell

8   Procedure and technique–step-by-step

- Make a 6–8 cm longitudinal lateral parapatellar incision on the anterolateral aspect of the knee. Begin 4–6 cm above the joint and extend the incision distally over the proximal tibia. The length of the distal extension will depend on the anatomy of the fracture and the technique used for fixation.
- Proximally deepen the approach in the line of the skin incision dividing the lateral patellar retinaculum and joint capsule. Distally expose the fracture line with minimum soft-tissue dissection.
- Incise the capsule horizontally below the level of the meniscus to obtain direct visualization of the articular surface. Take care to preserve a sufficient cuff of soft tissue to allow repair of the meniscus during closure.
- Expose the fracture and remove any debris and hematoma with a wash out and gentle use of a curette.
- Inspect the lateral meniscus and do not remove if torn and interposed, but rather place stay sutures to its lateral rim to fix the meniscus back upon wound closure.
- Open the fracture site to evaluate the extent of articular impaction.

- Use a laminar spreader or small self-retaining retractor to hold the fracture site apart, while the depressed articular fragments are elevated (Fig 3.15.2-6a).
- Remember that the articular surface of the lateral plateau is higher and convex compared with the concave medial plateau.
- Fill the metaphyseal defect, generated by elevating the articular fragments, with autogenous bone graft, bone graft substitute, or a mixture of the two.
- Check the reduction of articular surface by direct visualization and/or use of an image intensifier.
- Hold and fix the reduced lateral cortex with temporary K-wires (Fig 3.15.2-6b).
- Select a LCP-L buttress plate 4.5/5.0, left leg, of appropriate length to the lateral cortex. The plate may need contouring, using the plate bender and/or the bending irons. Ideally, the plate should be slightly under contoured so that it applies compression to the lateral tibial plateau as the screws are tightened. Make sure there is sufficient space for additional screws to be inserted proximal to the plate if needed.
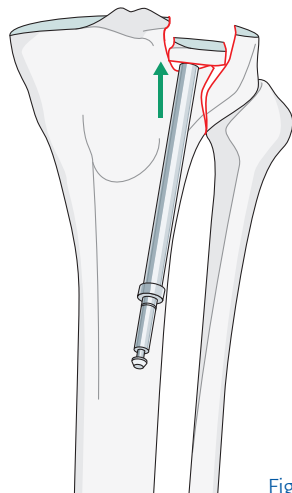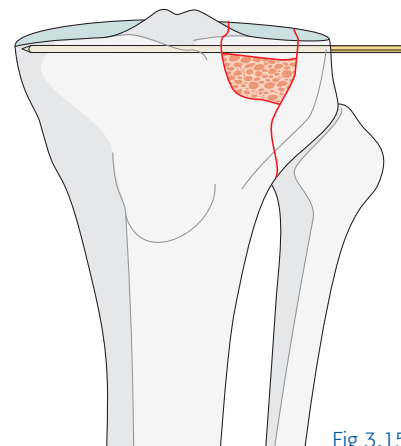

Fig 3.15.2-6a

Fig 3.15.2-6b

- Secure the plate to the tibial shaft with a single conventional cortex screw using the top (oval) hole on the shaft part of the plate. This allows for small adjustment of the plate position after screw insertion. Drill a 3.2 mm hole, measure the depth, tap the hole, and insert a 4.5 mm cortex screw of appropriate length (Fig 3.15.2-6c).
- Subchondral compression of the fracture can be achieved using two or more partially threaded 6.5 mm cancellous bone screws. Drill a 3.2 mm hole through one of the top plate holes. Take care not to penetrate the joint or the medial tibial cortex. Measure the depth, tap the lateral cortex, and insert an appropriate length partially threaded 6.5 mm cancellous bone screw. Make sure the entire threaded portion of the screw passes beyond the fracture site so compression is achieved (Fig 3.15.2-6d).
- As an alternative 7.0 mm partially threaded cannulated cancellous bone screws may be used, although the plate holes or a raft of 3.5 mm cortical lag screws may be placed just above the plate.

- Check the reduction and screw position with the image intensifier.
- Complete the fixation of the plate to the shaft of the tibia with the insertion of at least three 4.5 mm cortex screws or one or two additional locking head screws.
- Insertion of an additional optional oblique LHS (through the hole above the oval hole) may help reinforce the construct. Carefully select the appropriate drill bit for a LHS (4.3 mm) and perform the final tightening with the torque limiter (Fig 3.15.2-6e).
- Remove any K-wires.
- Take and save copies of final x-rays in both planes.
- Use the initially placed stay sutures to reattach the meniscus.
- Close the wound.
- Check the stability of the knee to valgus stressing. Although repair of a ruptured medial collateral ligament is rarely indicated, patients with instability may benefit from mobilization in a hinged brace.
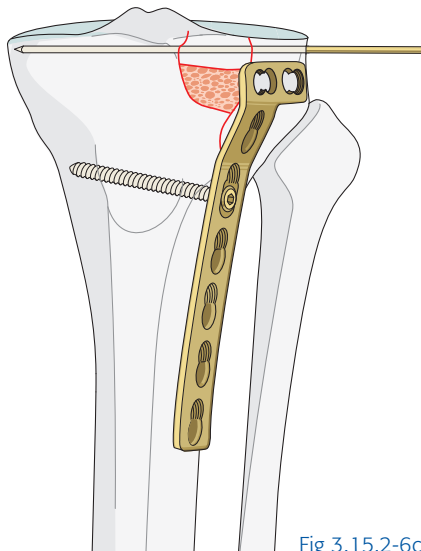

Fig 3.15.2-6c
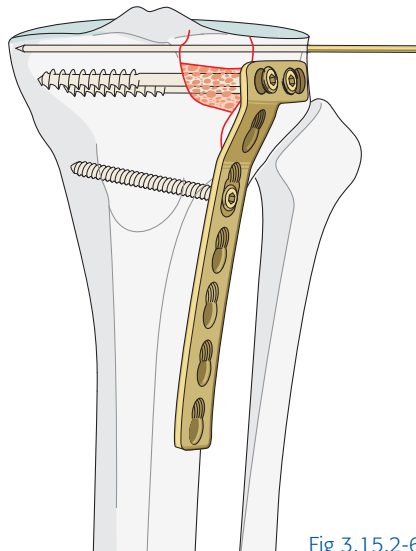
Fig 3.15.2-6d
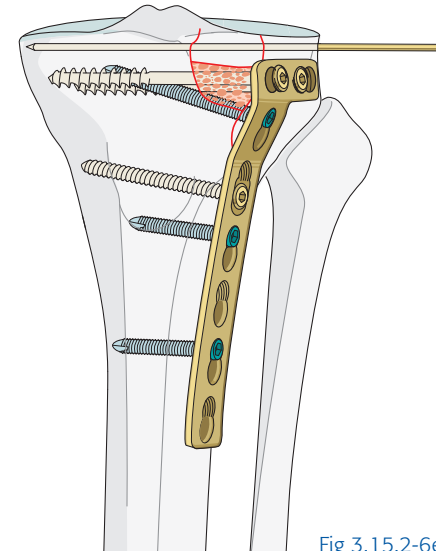
Fig 3.15.2-6e

Author   Peter Campbell

9   Specific perioperative care

- Be careful with pressure areas, particularly when subcutaneous nerves are at risk (both elbows and contralateral knee).
- Ensure tourniquet is correctly applied and inflated to correct pressure and not left inflated for too long.

- Maintain sterility as the image intensifier is rotated around the surgical field.

10   Specific postoperative care

- Take postoperative x-rays to check and document reduction and position of implant unless adequate hard or electronic copies were taken from the image intensifier.
- Start postoperative mobilization of the knee and patient as soon as possible provided the fixation is rigid enough to do so.
- Use of a continuous passive motion machine can support early movement until postoperative discomfort settles. Encourage active knee flexion and straight leg-raising exercises.

- Mobilize patients with partial weight bearing on crutches with, or preferably without, a hinged knee brace or cast. The hinges should be unlocked to allow maximum movement.
- Assuming clinical and x-ray evidence of progressive healing, full weight bearing can normally start after 6–8 weeks.

11   ORP—key points

- Cross-check that details of patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.

- Always check screw lengths and select correct thread length for cancellous bone screws.
- Confirm correct drill bit for the different screws.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of patient, side, marking, and site of surgery are correct.
- Draw up an appropriate plan and tactic for surgery before starting.
- Ensure satisfactory patient set-up.
- Ensure clear x-rays can be obtained in both planes.
- Take care when handling the soft tissues and fracture fragments to maintain blood supply and avoid devitalization.
- Be sure not to detach an intact meniscus during the approach, and if it is torn or interposed place stay sutures to facilitate repair after the elevation of the joint surface.
- Position reduction forceps and K-wires to take account of subsequent plate and screw placement. Avoid penetration of the medial cortex with wires or screws in metaphyseal region.
- Remember that the lateral plateau is higher and convex compared with the concave medial side.
- Be sure that the screw threads engage beyond the fracture line to provide interfragmentary compression and do not penetrate the joint.
- Do not over compress the plateau fragments, which can cause incongruity.
- Be careful when using an arthroscope that no fluid escapes from the knee into the calf to cause compartment syndrome.

Author   Peter Campbell

3.15.3   Complete articular fracture—articular complex, metaphyseal multifragmentary (41-C3): stabilization with LCP proximal lateral tibia plate (PLT) 3.5 and LCP proximal medial tibia plate (PMT) 3.5

Surgical management

- Stabilization with LCP proximal lateral tibia plate (PLT) 3.5 and LCP proximal medial tibia plate (PMT) 3.5

Alternative implants

- 6.5 mm partially threaded, cancellous bone screws and LCP-L buttress plate 4.5/5.0
- 7.0 mm cannulated screws
- 3.5 mm cortex screws
- LISS PLT (proximal lateral tibia) plate 5.0
- Ring or hybrid ring external fixator

1   Introduction
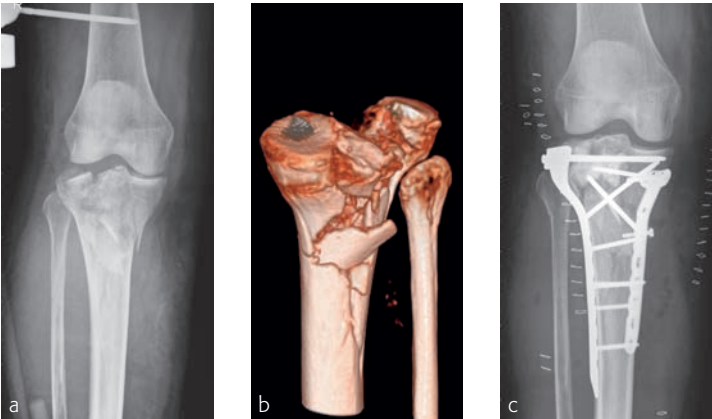
Fig 3.15.3-1a–c
a   Preoperative x-ray: complex bicondylar fracture of proximal tibia.
b   Preoperative CT scan: 3-D reconstruction of fracture showing severe communition and articular surface depression.
c   Postoperative x-ray: stabilization with two plates.

- These fractures are the most complex tibial plateau fractures and usually occur following high-energy trauma.
- They are characterized by complete separation of the metaphyseal fragments from the diaphysis.
- The soft tissues are always severely damaged in these cases.
- Applying a joint-bridging external fixator is standard practice to allow the soft tissue to recover before definitive surgery.
- The external fixator should be applied on or soon after admission with the Schanz screws placed outside the area of definitive surgery. The soft-tissue recovery may take from 10 days to as long as 3 weeks.
- Surgical management should minimize any further disruption to the soft-tissue envelope.
- These fractures require meticulous clinical and radiological preoperative assessment and planning.
- Obtaining a CT scan of the injury whenever facilities allow is mandatory (Fig 3.15.3-1b).

- Principles of fixation are based on the anatomical reduction, stable fixation of the joint surface which is then realigned with the diaphysis. Although fixation of the nonarticular elements of this fracture must be stable enough to allow early mobilization, their anatomical reduction is not an absolute requirement, provided rotation, alignment, and length have been restored.
- It may be advisable to use two separate incisions starting with the reconstruction of the medial plateau through a posteromedial approach, followed by the standard lateral approach.
- Surgical reconstruction may require referral to a more specialized surgical unit.
- The strategy outlined below describes the technique using two 3.5 mm precontoured LCPs. This may not be suitable for all such fractures. Surgery has to be exactly tailored to the individual fracture pattern as no two fracture of this complexity are similar.

- Alternative strategies include the initial reconstruction of the articular fragments using partially threaded 6.5 mm cancellous bone screws, 7.0 mm partially threaded, cannulated screws, or a raft of 3.5 mm cortex screws and a 4.5 mm buttress plate on the lateral side or the use of ring or hybrid ring external fixators.
- The fixation method used will ultimately depend on detailed fracture planning after consideration of the fracture configuration, soft-tissue damage, local resources, and local expertise.
- The use of bone graft or bone graft substitute to fill any defects in the metaphysis is optional.

Author   Peter Campbell

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed)
- Implants to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instrument and screw set 3.5/4.0 mm
- Instruments for removal of external fixator
- LCP proximal tibial plates lateral and medial 3.5 instrument and screw set
- Bone graft harvesting set
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Additional instruments that may be required:
- Laminar spreaders
- Femoral distracter or external fixator as a reduction aid (if not already applied)
- Partially threaded, cannulated screws 7.0 mm
- Osteotomes and curettes for bone graft harvesting
- Large reduction clamps

Equipment:
- Radiolucent operating table
- Table and positioning accessories to assist supine position and individual position of both legs
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- If regional anesthesia is used, appropriate measures must be in place to monitor compartment pressures in the lower leg muscle compartments. Compartment syndromes can occur, and if the patient is still under regional anesthesia he/she cannot complain of pain which is the earliest and most important symptom of compartment syndrome.

- The surgical time in this procedure is likely to exceed that of a spinal anesthetic, so it should be avoided.

4 Patient and x-ray positioning

- Position the patient supine on the operating table.
- Flexion of the knee up to 90° is required during surgery. This improves visualization of the joint surface and permits the iliotibial band to slip posteriorly from the lateral condyle. Obtain knee flexion either by "breaking" the table at the level of the knee and hanging the lower leg off the end of the table, or using a large bolster under the patient's thigh (Fig 3.15.3-2).
- Place the opposite leg supine on the operating table or into an abducted position with the hip and knee flexed to allow easier access for the image intensifier.
- Care must be taken to ensure that soft tissues, skin pressure points, and the subcutaneous nerves (ulnar nerve at the elbows and peroneal nerve of the opposite knee) are well protected.
- Adjust the operating table to the appropriate height and place the image intensifier on the opposite side of the injury, approaching the knee from the medial aspect.
- Ensure adequate posterior and lateral views can be taken.

Fig 3.15.3-2

Author   Peter Campbell

5   Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation.
- Disinfect the exposed area including the iliac crest and the foot with the appropriate antiseptic (Fig 3.15.3-3a).
- The joint-bridging external fixator must be disinfected with particular care.
- A sterile tourniquet may be applied after removal of the external fixator.

- Drape the limb with a single-use U-drape or extremity drape.
- Drape the iliac crest.
- A stockinette covers the foot and lower leg and is fixed with a tape (Fig 3.15.3-3b).
- Drape the image intensifier.
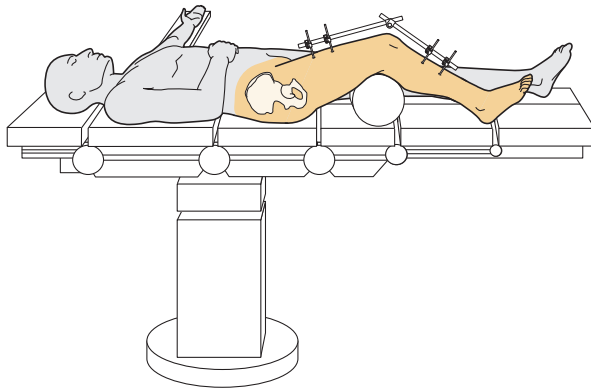
Fig 3.15.3-3a

Fig 3.15.3-3b

6 Operating room set-up

- The surgeon and the assistant stand on the side of the affected limb.
- The ORP stands next to the surgeon.
- Position the image intensifier on the opposite side of the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.15.3-4).

Fig 3.15.3-4

Author   Peter Campbell
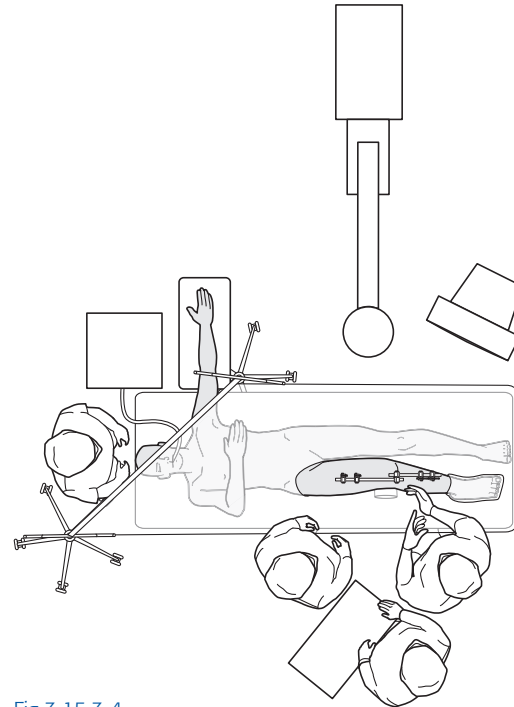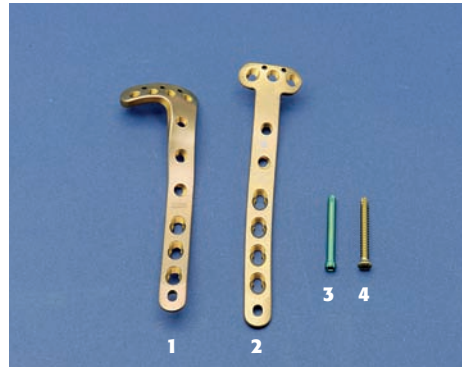
7   Instrumentation

Fig 3.15.3-5a   Implants for fixation of lateral tibia head
1. LCP proximal lateral tibia plate 3.5 right
2. LCP proximal medial tibia plate 3.5 right
3. Locking head screw 3.5 mm, self-tapping
4. Cortex screw 3.5 mm
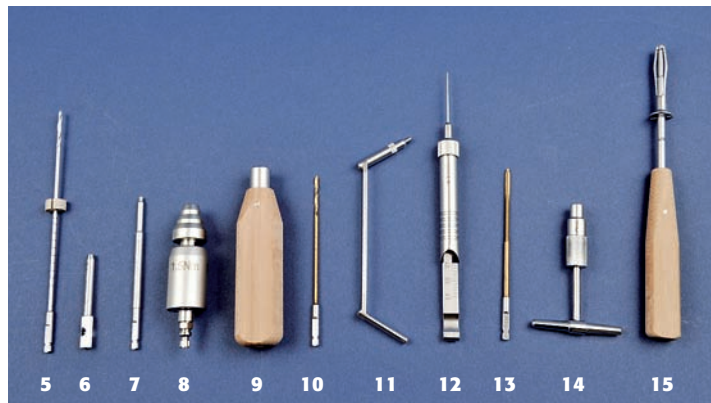
Fig 3.15.3-5b   Instruments for fixation of both LCP proximal tibia plates 3.5
5. LCP drill bit 2.8 mm
6. LCP drill sleeve 3.5 mm
7. Screwdriver shaft
8. Torque limiter 1.5 Nm with quick coupling
9. Handle with quick coupling
10. Drill bit 2.5 mm
11. Universal drill sleeve 3.5
12. Depth gauge
13. Tap 3.5 mm for cortex screw
14. T-handle
15. Screwdriver with holding sleeve

8 Procedure and technique–step-by-step

- Retain the external fixator which can be used to help achieve reduction.

Fixation of medial tibial plateau

- Start with fixation of the medial tibial plateau as this is usually the simpler fracture and easier to reduce anatomically.
- Palpate the posteromedial border of the proximal tibia. It is easily felt. Make a longitudinal incision over the bone. The length of the incision depends on the fracture anatomy and the length of the plate to be used. Divide the pes anserinus in the line of the skin incision and expose the bone avoiding excessive soft-tissue stripping.
- Reduce the medial fragment accurately under direct vision, making sure that the spike of the proximal fragment locks precisely into the distal part.
- A long 8-hole T-shaped LCP medial proximal tibia plate 3.5 (right) is used to span the proximal diaphyseal extension of the fracture. In other cases a shorter (4–5 hole) LCP plate 3.5 may be used as an alternative.
- Check that the contour of the plate matches the bone, and place it directly onto the medial crest of the tibia with the top of the plate below the level of the articular surface. Be aware there are right and left plate versions.
- Insert a first cortex screw through a combi hole of the plate just distal to the fracture, using the plate to push the fragments into place. Using the 3.5 mm universal drill sleeve drill a 2.5 mm hole, measure, and tap (with the gold-colored tap). Insert a 3.5 mm cortex screw. Tightening this screw will cause the plate to push the proximal fragment upward and laterally to lock the fragment in place (buttress or spring effect).

- Place a LHS screw through one of the holes in the top of the plate. This screw needs to secure the medial fragment but must not be so long as to prevent subsequent reduction of the lateral fragment. Insert a threaded drill guide into the selected hole and drill a 2.8 mm hole. Measure the depth and insert a short 3.5 mm LHS of appropriate length. Use the 1.5 Nm torque-limiting screwdriver and tighten the screw by hand (Fig 3.15.3-6a).
- The remaining fixation will be done once the lateral plateau has been reconstructed.

Fixation of lateral tibial plateau

- Make a 6–8 cm longitudinal lateral parapatellar incision on the anterolateral aspect of the knee. Begin 4–6 cm above the joint line and extend the incision distally over the proximal tibia. The length of the distal extension will depend on the anatomy of the fracture and the technique used for fixation.
- Proximally deepen the approach in the line of the skin incision dividing the lateral patellar retinaculum and joint capsule. Distally expose the fracture line with minimum soft-tissue dissection.
- Incise the capsule and make a horizontal incision below the level of the meniscus to provide direct visualization of the articular surface. Preserve a sufficient cuff of soft tissue to allow repair of the meniscus during closure.
- Place stay sutures into the usually torn or interposed lateral meniscus to facilitate its refixation once the lateral plateau has been elevated and reconstructed.
- Expose the fracture and remove any hematoma and debris with a wash out and a small curette.
- Open the fracture with the help of a laminar spreader or the distractor to evaluate the extent of articular damage and depression.

Author   Peter Campbell

- Remember that the articular surface of the lateral plateau is higher and convex compared with the concave medial plateau.
- Reduce the fragments of the lateral plateau using the reduced medial tibial plateau as reference, holding them in place with temporary 2 mm K-wires. Ensure the K-wires are placed so they do not interfere with subsequent plate placement (Fig 3.15.3-6b).
- Select an LCP proximal tibial plate 3.5 of appropriate length and side (right), and thread 2.8 mm threaded drill sleeves into two of the top plate holes to use as manipulation devices.
- Position the plate on the lateral border of the tibia and secure it with at least two 2.0 mm K-wires placed through the small holes in the top of the plate or through the threaded drill sleeves. The distal part of the plate may be held against the tibial shaft with reduction forceps (Fig 3.15.3-6c).

- Using both direct vision and the image intensifier, check the articular reduction and the position of the plate. The K-wires should be parallel to and just beneath the articular surface of the tibial plateau.
- The reconstructed articular block is now supported with 3.5 mm LHS inserted through the 4 holes in the horizontal part of the plate, replacing K-wires where necessary. The screws should extend to, but not through, the far cortex. Drill a hole with a 2.8 mm drill bit through the threaded drill sleeve, read the depth off the drill bit, and insert an appropriate length LHS using the 1.5 Nm torque-limiting screwdriver for final tightening (Fig 3.15.3-6d).
- Secure the plate to the tibial shaft distal to the fracture using a conventional 3.5 mm cortex screw. Drill a 2.5 mm hole,
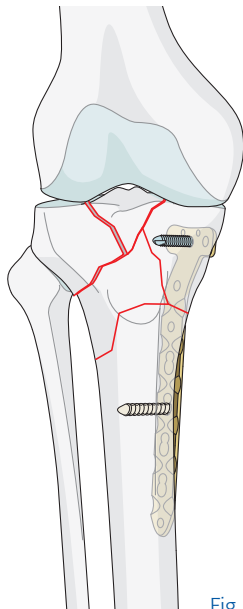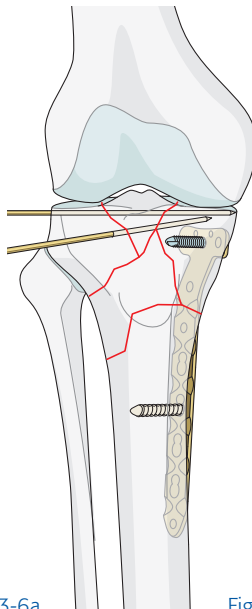

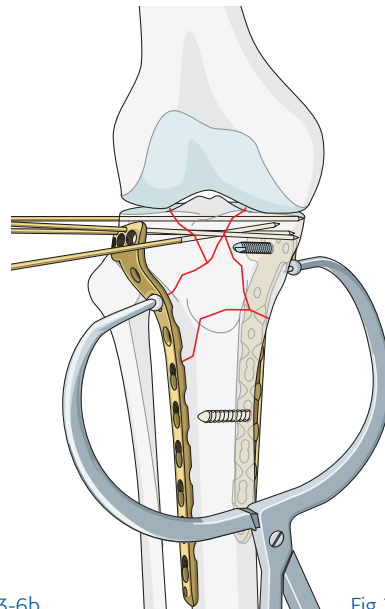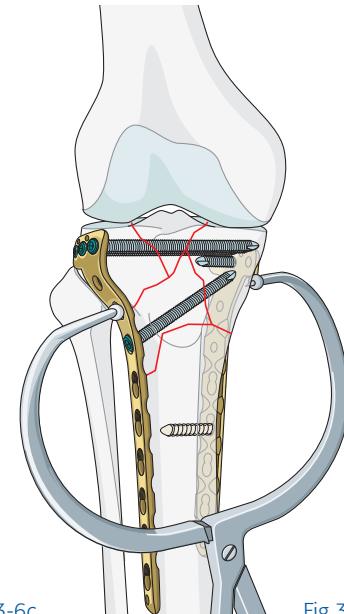Fig 3.15.3-6a   Fig 3.15.3-6b   Fig 3.15.3-6c   Fig 3.15.3-6d

measure the depth, tap the hole, and insert a 3.5 mm cortex screw of appropriate length (Fig 3.15.3-6e). Tightening this screw will create a buttress effect providing some compression at the articular surface.

■ Reinforce the fixation of the lateral plate with additional cortex or LHS inserted into the shaft of the tibia, depending on the bone quality (Fig 3.15.3-6f). Additional LHS may be inserted into the 3 holes between the top of the plate and the combi holes. These are designed to provide additional support and fixation to the metaphysis without penetrating the joint.

■ Return to the medial side to finalize the fixation of the medial plate. Put in additional long LHS proximally to help support the articular fragments and LHS or cortex screws distally to reinforce the plate fixation to the tibial shaft (Fig 3.15.3-6g).

■ The metaphyseal defect generated by elevating the articular fragments may be filled with bone graft or bone substitute to support the articular fragments. Although with the increased stability due to the locking head screws that create a raft below the joint surface, some surgeons no longer use a bone graft. In this case a bone substitute is used.

■ Check clinically and by image intensifier to ensure that tibial length, rotation, and axial alignment have been restored and the plates are correctly placed on the shaft of the tibia.

■ Check the stability of the knee to assess for associated ligament injuries.

■ Perform a final check of the reduction of the articular surface by direct vision and with the image intensifier.

■ Take and save copies of final x-rays in both planes.

■ Reattach the lateral meniscus.

■ Close the wounds.

Further information is available on AO Teaching video 20226: Tibial Plateau Bicondylar Fracture C3 LCP 4.5/5.0 Proximal Tibial Plate.
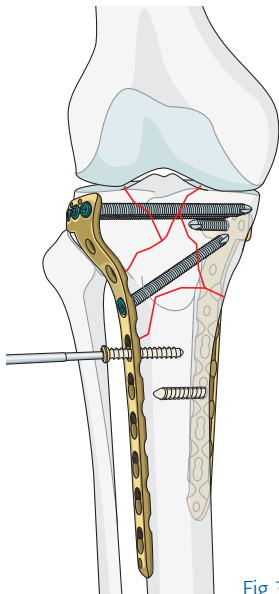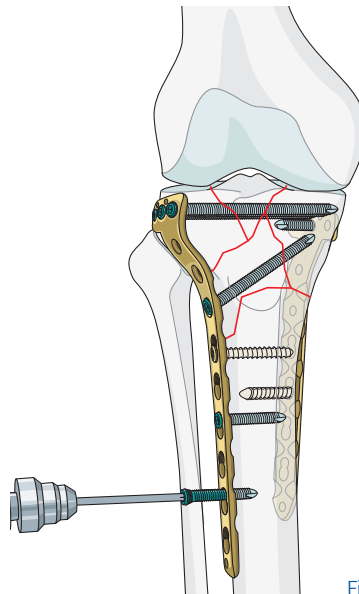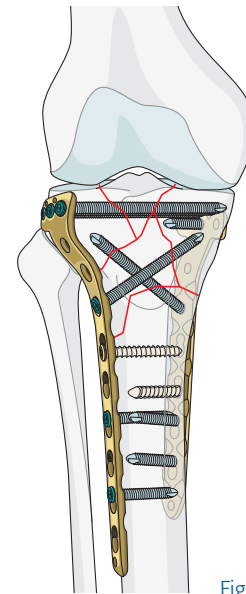

Fig 3.15.3-6e

Fig 3.15.3-6f

Fig 3.15.3-6g

Author   Peter Campbell

9   Specific perioperative care

- Be careful with pressure areas, particularly when subcutaneous nerves are at risk (both elbows and contralateral knee).
- Ensure tourniquet is correctly applied and inflated to correct pressure. This procedure can take time, and deflation of the tourniquet may be required before the end of the operation to avoid neuropraxia.

- Maintain sterility as the image intensifier is rotated around the surgical field.

10   Specific postoperative care

- Take postoperative x-rays to check and document reduction and position of implant unless adequate copies were taken from the image intensifier.
- Start active mobilization as soon as possible, provided the fixation is considered stable.
- Use a continuous passive motion machine to provide early movement until postoperative discomfort settles.

- Mobilize the patient with partial weight bearing (10 kg) with crutches, with or preferably without a hinged knee brace or cast. The hinges should be unlocked to allow maximum movement.
- Assuming clinical and x-ray evidence of progressive healing, full weight bearing can normally begin after 8–12 weeks.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Check that correct right and left plate versions are available.
- Be prepared for application of different types of plates and screws.

- Prepare instruments for readjusting and removing external fixator.
- Consider bone grafting, or bone graft substitution.
- Remember cooling while drilling locking head screws.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Ensure meticulous preoperative clinical and x-ray assessment.
- Ensure fracture complexity does not exceed local resources or skills. If in doubt, apply a temporary bridging external fixator and discuss the images with a specialist center. The patient may need transfer for definitive fixation.
- Prepare a detailed surgical plan and tactic before surgery which should also be given to the ORP.
- Ensure satisfactory patient set-up in the operating room, and that clear x-rays can be obtained in both planes.
- Make sure the soft tissues and fracture fragments are handled carefully to preserve blood supply and avoid devitalization.
- Start with the fixation of the simpler, usually medial fracture component, through a separate posteromedial incision.
- In most complex fractures a posterior approach with the patient prone may be required initially and he/she may need to be repositioned and redraped before the second incision is made. This should be anticipated and planned.
- Do not use a single long anterior incision if two plates are to be used. Single incisions involve extensive subcutaneous dissection and have a high risk of wound breakdown.

- If detaching the lateral meniscus during the approach to the lateral plateau, ensure sufficient soft-tissue cuff to allow adequate repair. Use stay sutures that are placed initially for easier refixation of the meniscus.
- Position reduction forceps and K-wires to take into account subsequent plate and screws. This particularly applies when using locking head screws, as the predetermined angle through the plate cannot be altered.
- Significant fracture fragments that are not held in place by the plates may require fixation with a separate lag screw.
- Always complete insertion of locking head screws with the torque-limiting screwdriver.
- If a combination of cortex and locking head screws is used in the shaft of the plate, the cortex screw should be applied first to pull the plate to the bone.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.16   Tibial shaft fractures

3.16   Tibial shaft fractures

Implants and surgical technique

- Expert tibial nail (ETN)
- Large tubular external fixator
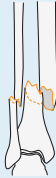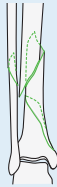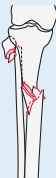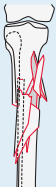
Cases

- Diaphyseal tibial fracture (42-A1)
- Diaphyseal open tibial fracture (42-B1)

Introduction

- According to the Müller AO/OTA Classification, tibial shaft fractures are described as bone-4, segment-2 with the subdivisions:
    - 42-A1, 2, and 3: simple fractures
    - 42-B1, 2, and 3: wedge fractures
    - 42-C1, 2, and 3: complex fractures
- Clinical evaluation must include physical examination of peripheral pulses, sensation, and muscle function.
- Careful assessment and management of the soft tissues is the key to the successful treatment of both open and closed tibial shaft fractures.
- Temporary stabilization of fractures with external fixation may be required in open fractures and in closed injuries with extensive soft-tissue damage. Such staged management will allow the soft tissues to recover sufficiently to allow definitive fixation.

- In multiple-injury patients temporary use of an external fixator (damage control) allows rapid stabilization of fractures with minimal additional trauma to the patient.
- The development of a compartment syndrome is common following tibial shaft fractures. A compartment syndrome must be excluded on admission and the patient must be carefully monitored for the first few days after admission or surgery.
- Minimally displaced, stable fractures of the tibia and fibula may be successfully managed nonoperatively with an above-knee cast followed by a weight-bearing Sarmiento-type below-knee brace. Such a fracture can also be treated surgically.
- Unstable, displaced, complex, or open fractures of the tibia are best treated surgically.

Müller AO/OTA Classification—tibia/fibula: diaphyseal segment

| 42-A1 | 42-A2 | 42-A3 | 42-B1 | 42-B2 | 42-B3 | 42-C1 | 42-C2 | 42-C3 |

42-A   simple fracture
42-A1   spiral
42-A2   oblique (≥ 30°)
42-A3   transverse (< 30°)

42-B   wedge fracture
42-B1   spiral wedge
42-B2   bending wedge
42-B3   fragmented wedge

42-C   complex fracture
42-C1   spiral
42-C2   segmental
42-C3   irregular

Author   Paulo Barbosa

3.16.1   Diaphyseal tibial fracture (42-A1): stabilization with expert tibial nail (ETN)

Surgical management

- Indirect reduction and stabilization with expert tibial nail (ETN)

Alternative implants

- Large external fixator
- LCP 4.5/5.0 narrow
- LC-DCP 4.5 narrow
- DCP 4.5 narrow
- Universal tibial nail

1   Introduction

- Intramedullary nailing is indicated for most closed, and for many open, fractures (Gustilo I, II, and IIIA) of the tibial shaft.
- Intramedullary nails may be inserted with or without reaming of the medullary canal. Reaming allows the use of a larger diameter nail and is the preferred method for closed fractures. Nail insertion without reaming may have some advantages in open fractures.
- The ETN is available in a solid version (8–10 mm) to be inserted without reaming, and a cannulated version (8–13 mm) for insertion using a reamed or unreamed technique.
- New nail designs (such as the ETN) have expanded the indications of intramedullary nailing to the metaphyseal areas of the proximal and distal tibia because of the additional options for the placement of locking screws.

Fig 3.16.1-1a–b   Tibial shaft fracture (42-B2): stabilized with a reamed IMN-ETN.
a   Preoperative x-ray: short oblique tibial shaft fracture.
b   Postoperative x-ray: stabilization using expert tibial nail.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (fracture open or closed/compartment syndrome)
- Nail to be used (with or without reaming)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Traction pin set for calcaneal traction (if fracture table is used)
- Nailing instrument set—ETN
- ETN implant selection
- Synream (reamer set)
- Two reaming rods, short, 950 mm
- Handreamer set
- Large distractor or external fixator (optional)
- General orthopaedic instruments
- Compatible air or battery drill with attachments
- Radiolucent drive

Equipment:
- Standard radiolucent operating table, which may be reconfigured as a fracture table
- Table and positioning accessories to assist supine position and individual positioning of both legs
- Image intensifier
- X-ray protection devices for personnel and patient

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- Postoperatively avoid giving long-lasting complete pain blocks for the injured leg, as this could hide symptoms of a subsequent compartment syndrome.

Author   Paulo Barbosa

4   Patient and x-ray positioning

Tibial nailing is performed on a standard radiolucent table or on a fracture table. Both set-up methods are described:

Tibial nailing on a standard radiolucent table

- Ensure the whole leg below the pelvis lies in the radiolucent segment of the table to allow the image intensifier to move freely.
- For the nail insertion the knee of the affected limb should be flexed to at least 90º. This can be done with or without a triangular support. If support is used, it must not be placed into the popliteal fossa but under the thigh (Fig 3.16.1-2a).
- Alternatively, the leg can be supported by a well-padded support under the distal thigh allowing the knee to be held fully flexed for nail insertion (Fig 3.16.1-2b).
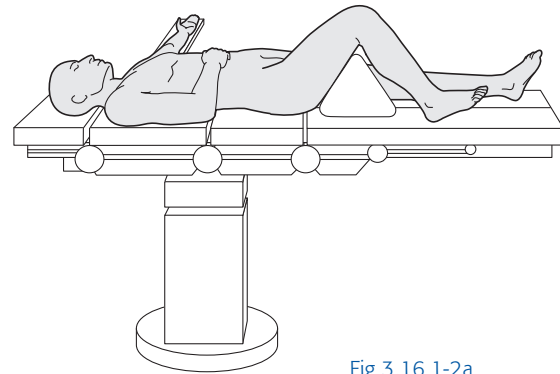
Fig 3.16.1-2a
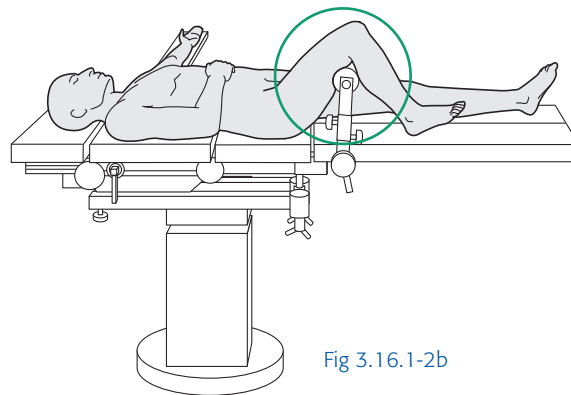
Fig 3.16.1-2b
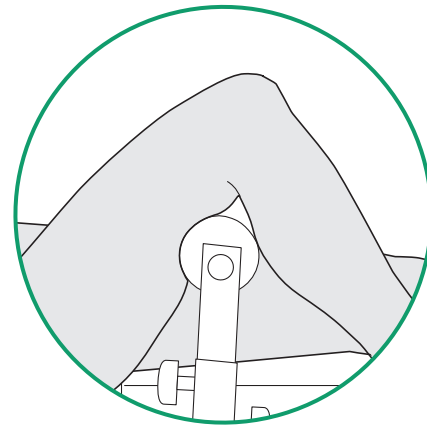
Tibial nailing on a fracture table

- Disinfect the skin of the heel.
- Drill a 2 mm K-wire through the calcaneus and attach a traction bow to it.
- Reconfigure the table, or transfer the patient to a fracture table.
- Place the opposite leg out of the way in a gynecological leg holder to allow access for the image intensifier. Alternatively, place the uninjured leg in full extension with special care not to interfere with the lateral view of the distal one-third of the injured leg (Fig 3.16.1-2c).
- Mount a padded support under the distal end of the thigh of the affected leg, avoiding the popliteal fossa and flex the knee 90º.
- Fix the traction bow to the traction support arm of the fracture table and apply straight traction to the injured leg.
- Place the image intensifier on the opposite side of the table and check that adequate AP and lateral views of the length of the tibia are obtained.
- Unlock table joints; reduce the fracture (usually by traction, and external/internal rotation). Relock joints once this has been achieved.
- Take care with soft tissues and skin pressure points.

Fig 3.16.1-2c

Author   Paulo Barbosa
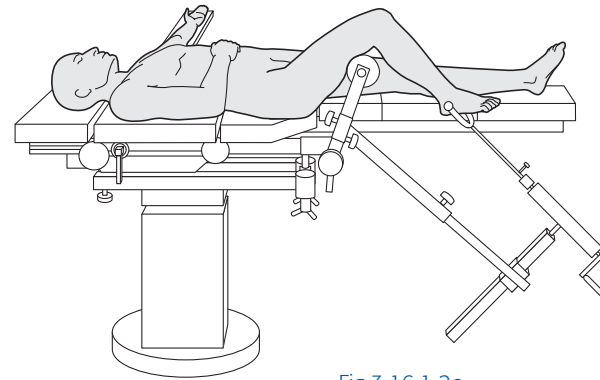
5   Skin disinfecting and draping

- Maintain light manual traction on the limb (if it is not already in traction) during preparation to avoid excessive deformity at the fracture site.
- Disinfect the exposed area from the hip distally, including the foot with an appropriate antiseptic (Fig 3.16.1-3a).
- Drape the limb with a single-use U-drape or extremity drape. A stockinette (or sterile glove) covers just the foot and is fixed with a tape. Take care not to hide the distal-locking screw positions (Fig 3.16.1-3b).

- Drape the leg so as to be freely moved.
- Flex the knee over a well-padded support.
- Drape the image intensifier.
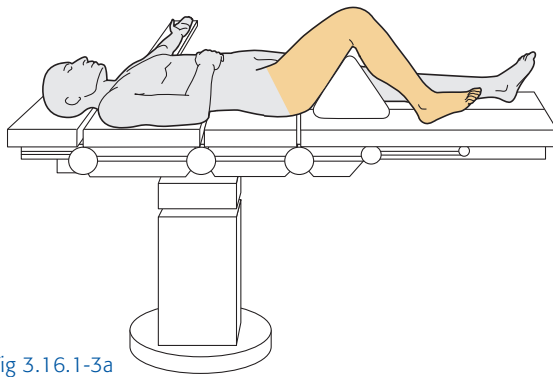
Fig 3.16.1-3a
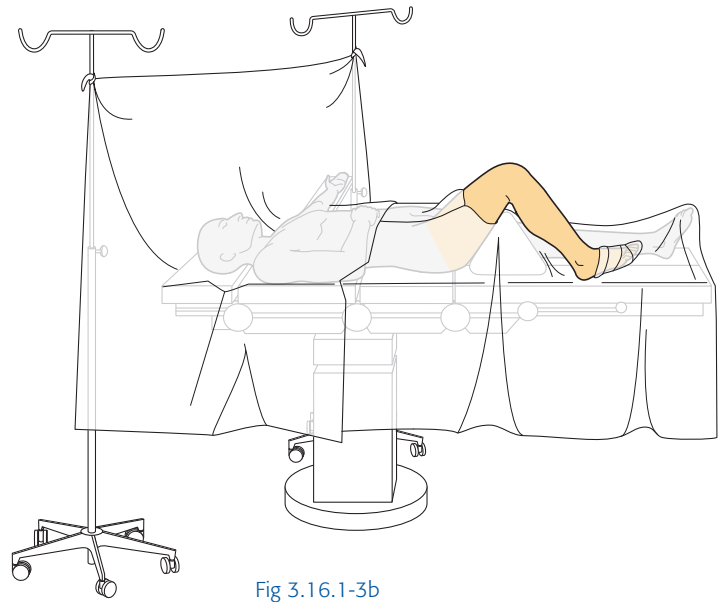
Fig 3.16.1-3b

6 Operating room set-up

- The ORP and surgeons stand on the lateral side of the affected limb.
- Position the image intensifier on the opposite side of the table medial to the fracture, perpendicular to the long axis of the tibia.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.16.1-4).

Fig 3.16.1-4

Author   Paulo Barbosa
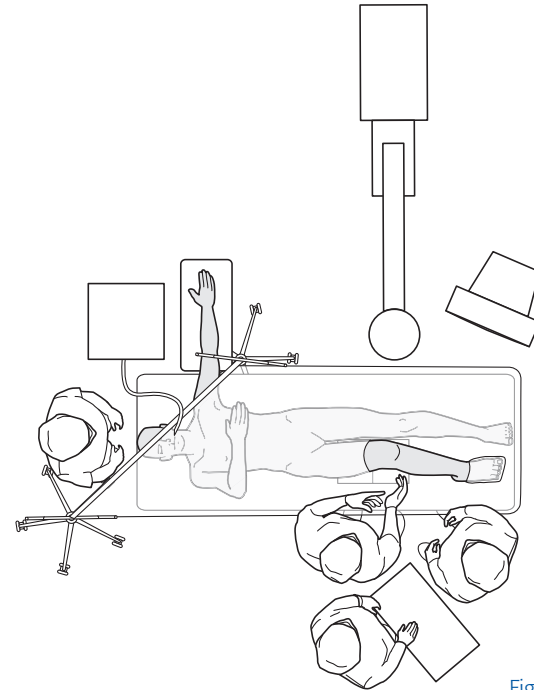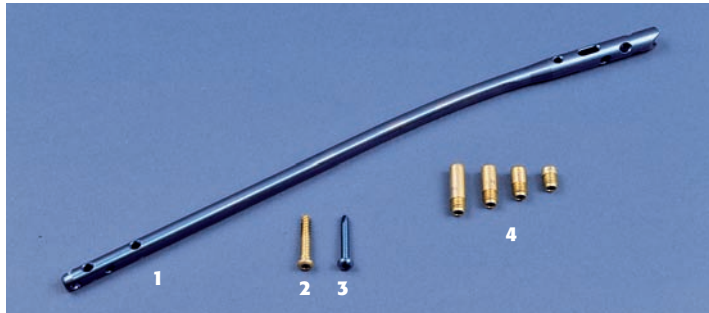
7   Instrumentation

Fig 3.16.1-5a   Implants
1.   ETN
2.   Locking screw 4.0 mm
3.   Cancellous bone locking screw 5.0 mm
4.   End caps
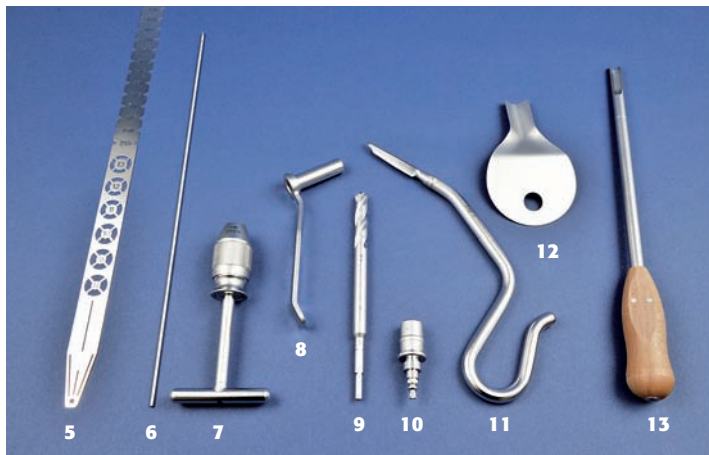
Fig 3.16.1-5b   Instruments for opening of medullary canal and nail size determination
5.   Radiographic ruler
6.   Guide wire 3.2 mm
7.   Universal chuck with T-handle
8.   Protection sleeve 14/12 mm
9.   Drill bit 12 mm
10.   DHS/DCS quick coupling
11.   Awl, cannulated
12.   Tissue protector
13.   Cutter for tibial nail
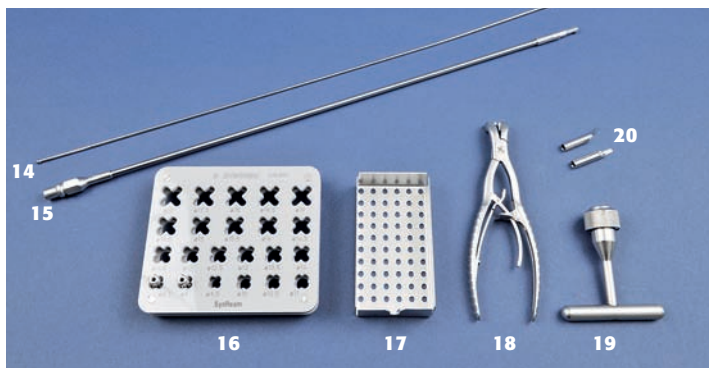
Fig 3.16.1-5c   Instruments for intramedullary reaming
14.   Reaming rod 2.5–950 mm
15.   Flexible shaft
16.   Tray with reamer heads
17.   Removing tool
18.   Holding forceps for reaming rod
19.   T-handle
20.   Reduction heads, straight and curved

Fig 3.16.1-5d Instruments for nail insertion
21. Insertion handle
22. Connecting screw
23. Screwdriver with spherical head
24. Connector for insertion handle
25. Combination wrench 11 mm
26. Pin wrench
27. Hammer guide
28. Slide hammer
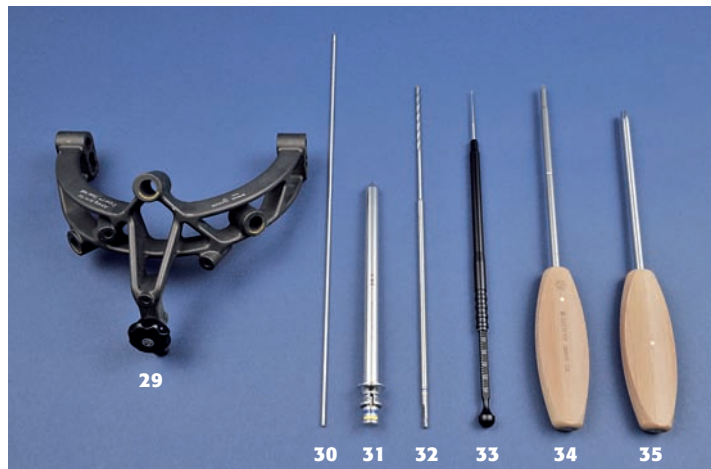
Fig 3.16.1-5e Instruments for proximal locking
29. Aiming arm
30. Guide wire 3.2 mm
31. Triple drill sleeve assembly (protection sleeve 12/8.0 mm, drill sleeve 8.0/3.2 mm, and trocar 3.2 mm)
32. Drill bit 3.2 mm
33. Depth gauge
34. Screwdriver for locking screws
35. Screwdriver for end cap

Author Paulo Barbosa

Fig 3.16.1-5f Instruments for distal locking
36. Radiolucent drive
37. Drill bit 3.2 mm for radiolucent drive
38. Direct measuring device
39. Screwdriver for locking screws with holding sleeve

Fig 3.16.1-5g Instruments for implant removal
40. Screwdriver for locking screws
41. Screwdriver for end cap
42. Extraction screw
43. Combination wrench 11 mm
44. Pin wrench
45. Hammer guide
46. Slide hammer

8 Procedure and technique—step-by-step

- Measure the required nail diameter and length using the radiographic ruler over the reduced tibia in the AP view (Fig 3.16.1-6a). Alternatively, make the measurement beforehand on the uninjured tibia of the opposite leg.
- With the knee flexed make a longitudinal incision over the patellar tendon starting proximally at the inferior margin of the patella and running down to the tibial tuberosity.
- Incise the tissue on the medial aspect of the patellar tendon and retract the tendon laterally. Alternatively, split the tendon longitudinally in its midline.

- Choosing the correct nail entry point is crucial. In the AP view it lies in line with the medullary canal and in the lateral view it starts at the ventral ridge of the tibial plateau (Fig 3.16.1-6b–c).
- Check the entry point in both AP and lateral views using image intensification.
- Secure the 3.2 mm guide wire in the universal chuck with the T-handle.
- Insert the guide wire at the entry point for approximately 8–10 cm, in line with the long axis of the tibia in the AP view but aiming posteriorly at a 10º angle to the axis of the tibial shaft on the lateral view (Fig 3.16.1-6d). An ETN can be used as a template to obtain the correct angle. Check the position of the wire with the image intensifier.
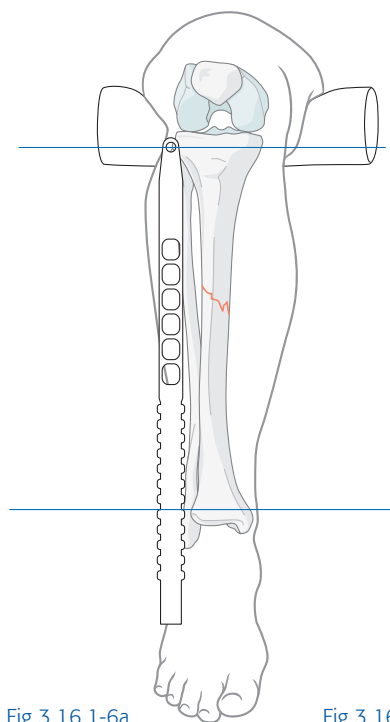
Fig 3.16.1-6a
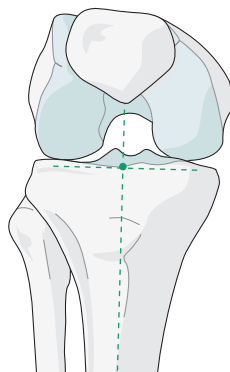
Fig 3.16.1-6b
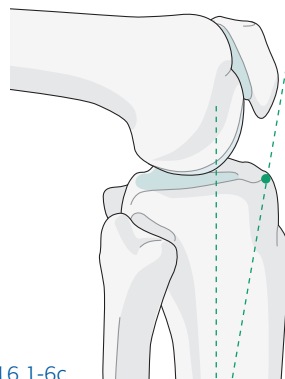
Fig 3.16.1-6c

Fig 3.16.1-6d

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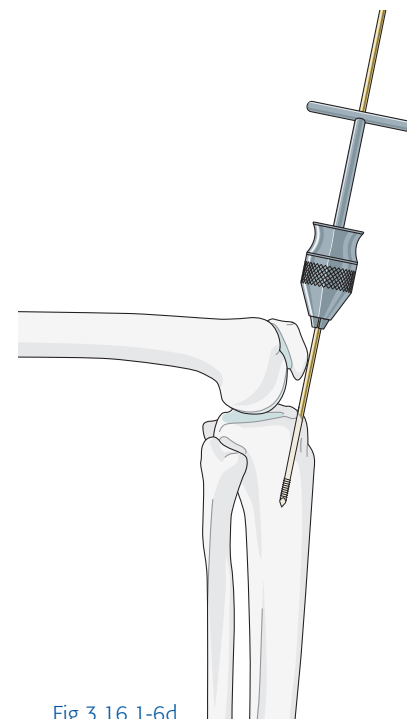
- Slide the protection sleeve and the cutter over the guide wire to open the medullary canal to a depth of 8–10 cm. Take care not to damage the posterior cortex of the tibia (Fig 3.16.1-6e).
- In case of very dense bone in young patients, the proximal opening can be made with a 12 mm cannulated drill bit over the same guide wire and protection sleeve or with a hand-held awl.
- Remove the guide wire, cutter, and protection sleeve.

- Insert the Synream reaming rod 2.5 mm into the medullary canal to the level of the fracture (Fig 3.16.1-6f). Reduce the fracture or hold it reduced, and pass the reaming rod across the fracture site.
- Check the position of the rod in the distal tibia with the image intensifier (Fig 3.16.1-6g).
- Using the image intensifier, ensure the tip of the reaming rod is lying in the center of the distal tibial metaphysis in both
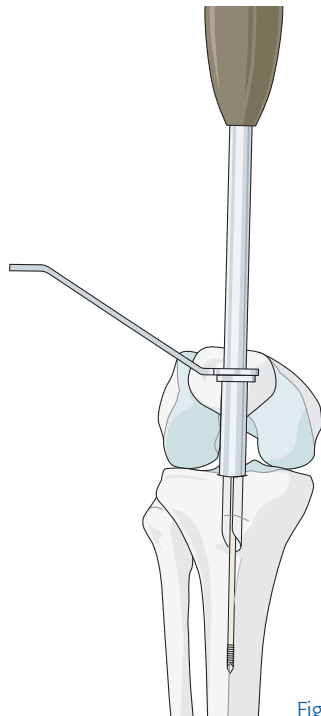
Fig 3.16.1-6e
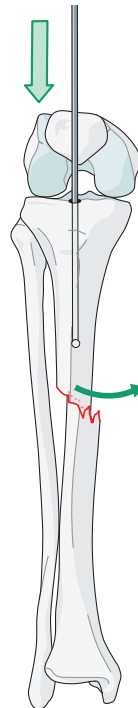
Fig 3.16.1-6f
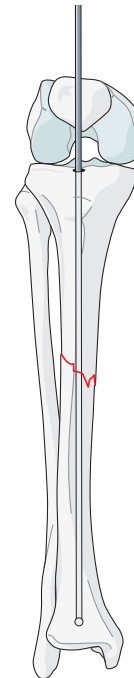
Fig 3.16.1-6g

planes. Correct the position if it is not well centered. This is particularly important in distal tibial fractures.

- The most common cause of an imperfectly centered reaming rod is the failure to reduce the fracture before passing the rod across the fracture site. The nail will not reduce the fracture during insertion in fractures occurring in the proximal or distal thirds of the tibia.

- Confirm the length of the nail with a radiographic ruler or with a second reaming rod and a ruler. The portion of the second rod beyond the top of the one in the tibia defines the length of the nail.

- Pass the flexible reaming shaft, starting with the 8.5 mm front cutting reamer head, over the reaming rod (Fig 3.16.1-6h).

- Ream up to a diameter of 0.5–1.5 mm larger than the selected ETN in 0.5 mm increments with the reaming heads.

Fig 3.16.1-6h

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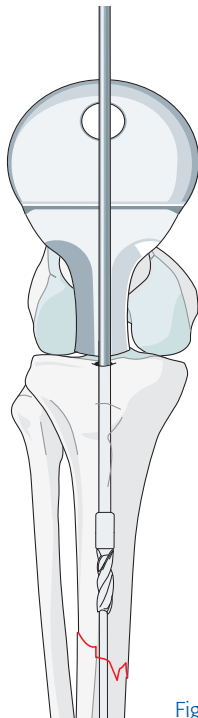
- Advance the reamer at full speed with continuous, moderate pressure but do not apply any force. If it stops advancing, retract the reamer to clear the cutting flutes of debris.
- Use the holding forceps to prevent the reaming rod from backing out during reamer extraction.
- There is no need to exchange the Synream reaming rod before nail insertion, as it has only a small olive at the distal end that will pass through the nail.
- Connect the selected ETN to the insertion handle using the connection screw and the corresponding screwdriver with spherical 8 mm head (Fig 3.16.1-6i).
- Make sure the notch of the handle faces anteriorly and matches the nail correctly.
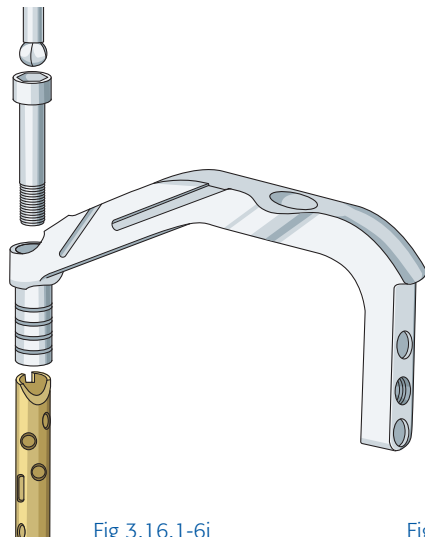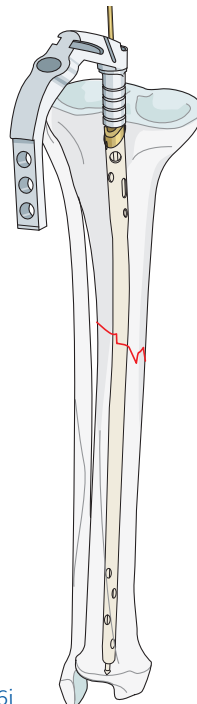
Fig 3.16.1-6i   Fig 3.16.1-6j

- For nail insertion, hyperflex the knee and place the foot on a stable surface.
- Insert the assembled ETN over the reaming rod and advance it with steady force and twisting movements.
- Using the image intensifier, monitor the passage of the nail across the fracture site to ensure the correct position.
- If needed, use light, controlled hammer blows to advance the nail. Slide the connector into the grooves on the insertion handle and strike the connector directly.
- Advance the nail until the proximal end is at, or below the level of the opening, the proximal nail entry point. Check the final position at the fracture site and the distal end of the tibia in AP and lateral views (Fig 3.16.1-6j).
- Remove reaming rod.
- If inserting a solid ETN without reaming, the opening procedure of the proximal tibia is as described for a reamed nail, but the reaming rod is then removed and the nail inserted and guided across the fracture site using the image intensifier.
- Check the final position of the proximal end of the nail by attaching the aiming arm for ETN to the insertion handle and insert a 3.2 mm guide wire through the small hole in front of the aiming device. The tip of this guide wire indicates the exact proximal position of the nail. Ensure that the nail does not protrude into the knee.

Locking the nail

- Surgical opinion differs as whether to lock proximally or distally first. In shaft fractures it is recommended to lock distally first, enabling the use of the backstroke technique to close up a fracture gap or the use of the compression device to achieve better bone contact in transverse fractures. If a backstroke or compression is planned, the nail should be overinserted by 5–10 mm.
- The nails, drill sleeves, and screws are color coded to help select the correct diameter screw and guide for the nail.

Distal locking

- Distal locking of the tibial nail is performed from the medial side with the free-hand technique. Using the radiolucent drive facilitates the aiming procedure. The number of locking screws required depends on the site and type of the fracture.
- Ensure the image intensifier is directed in such a way that the x-ray beam points away from the surgeon's side to the screen on the opposite side.
- Align the C-arm with the hole in the nail closest to the fracture until a perfect circle is visible on the screen (the distal hole shown in the illustration) (Fig 3.16.1-7a).
- Do not attempt to adjust the position of the leg to align the

holes; this may cause loss of rotational alignment at the fracture site. You may tilt the table.
- Place a scalpel blade on the skin over the center of the hole to mark the incision point and make a stab incision (Fig 3.16.1-7b).
- Dissect down to the bone using a blunt instrument.
- Position the tip of the corresponding sharp drill bit (3.2 or 4.2 mm) obliquely through the incision. Using the image intensifier position the tip of the drill bit over the center of the hole. Hold it firmly in place (Fig 3.16.1-7c).
- Ensuring that the sharp drill bit tip does not move on the bone, change the angle of the drill bit until it is exactly aligned with the direction of the image intensifier beam (Fig 3.16.1-7d).
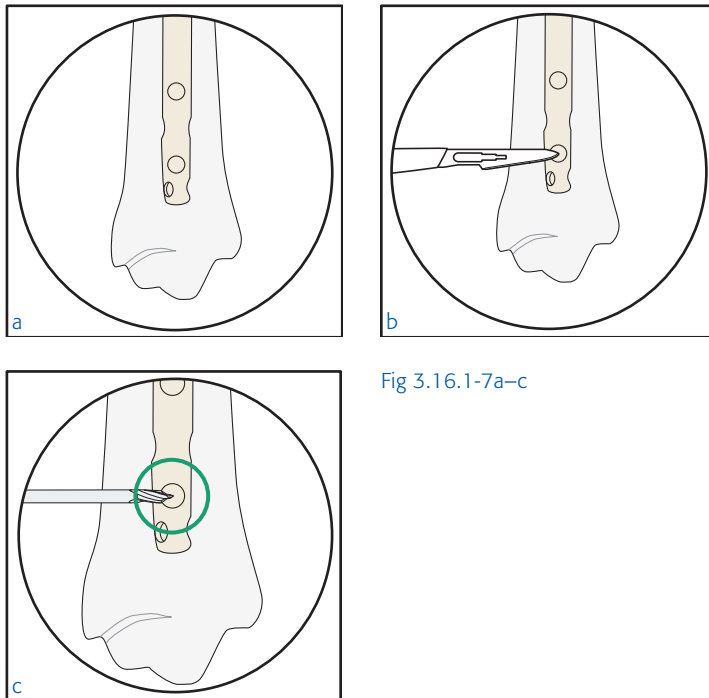
Fig 3.16.1-7a–c

Fig 3.16.1-7d

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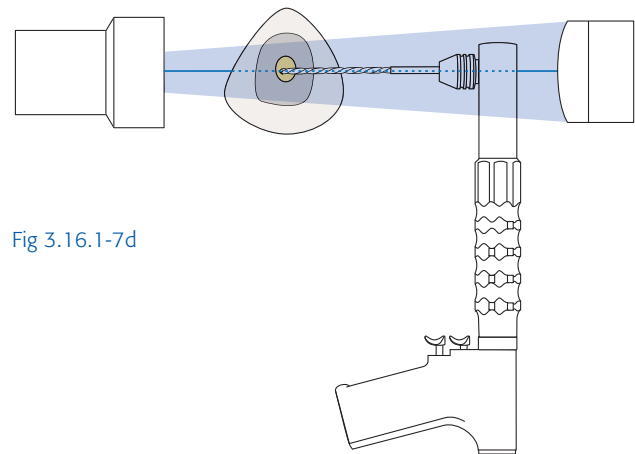
- Now drill the hole of the first cortex without slipping on the bone surface. Stop drilling and manually guide the drill bit through the hole in the nail before drilling the far cortex.
- If no sharp-tipped drill bit is available, it may be easier to indent the bone over the center of the hole in the nail with a short Steinmann pin and a hammer before attempting to drill a hole. This reduces the risk of the drill slipping on the bone when drilling is initiated.
- Verify with the image intensifier that the drill bit lies within the hole of the nail.
- Measure the screw length using the depth gauge. Ensure the outer sleeve is in contact with the bone and the hook grasps the far cortex.
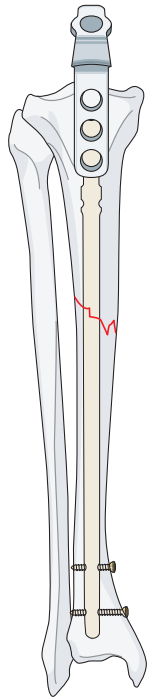
Fig 3.16.1-7e

- Alternatively, dissemble the drill bit from the radiolucent drive and insert the direct measuring device on the drill bit. Note that exact drill bit location with respect to the far cortex is critical for this type of measurement.
- If the drill has depth calibrations, the length can be read directly from the drill bit. If necessary, this should be checked using the image intensifier.
- Insert the appropriate length 4.0 or 5.0 mm locking screw using the stardrive screwdriver and the holding sleeve, if needed. The holding sleeve grips the locking screw to prevent loosing it in the soft tissues.
- Verify screw length under image intensification.
- Generally, a second distal locking screw is inserted using the same technique (Fig 3.16.1-7e).

Proximal locking
- The ETN has several options for proximal locking. The option of multiplanar screw directions is particularly helpful when securing fixation in proximal fractures. For most diaphyseal fractures the standard medial-to-lateral proximal holes are sufficient and allow for later dynamization.
- Before proximal locking check the rotation and length of the leg and compare it with the other side.
- A gap at the fracture site should be avoided and closed by knocking the nail out slightly after securing distal fixation (backstroking) or by use of the compression screw.
- Because the insertion handle may loosen during insertion of the nail, again tighten the bolt attaching the insertion handle to the nail. A loose connection will cause malalignment of the aiming arm. Mount the aiming arm on the insertion handle (Fig 3.16.1-8a).
- Insert the three-part trocar combination through the desired medial hole in the aiming arm, make a stab incision in the skin, and push the trocar down to the bone (Fig 3.16.1-8b). Remove the trocar.

- Using the corresponding drill bit (3.2 mm for 4.0 mm locking screws or 4.2 mm for 5.0 mm locking screws), drill through both cortices.
- Read the screw length from the calibrated drill bit just before it penetrates the far cortex. Remove drill bit and drill sleeve.
- Alternatively, use the measuring device, reading the measurement from the top end of the protection sleeve.

- Select the appropriate length and size of the locking screw.
- Insert the locking screw through the protection sleeve using the stardrive screwdriver (Fig 3.16.1-8c). The tip of the locking screw should not project more than 1–2 mm beyond the far cortex.
- Repeat the steps for the second proximal locking screw.
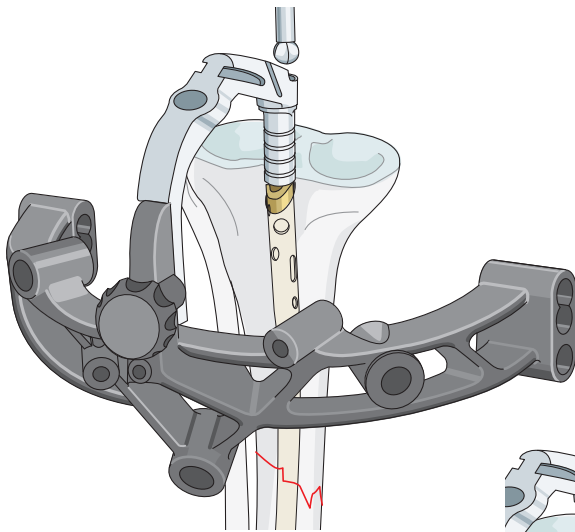
Fig 3.16.1-8a
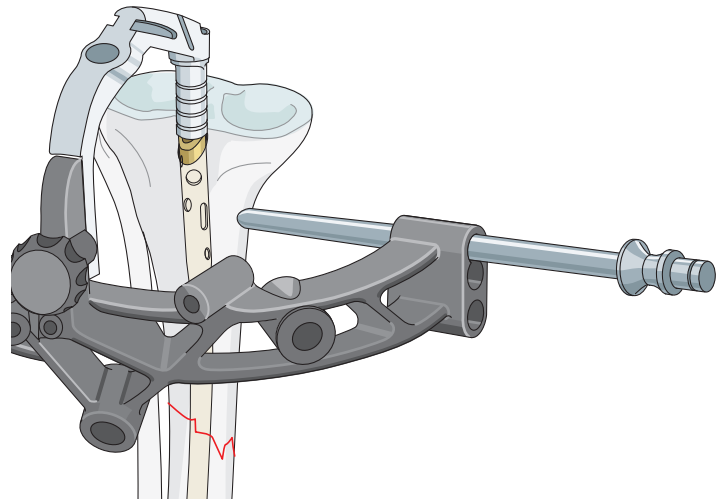
Fig 3.16.1-8b

Fig 3.16.1-8c

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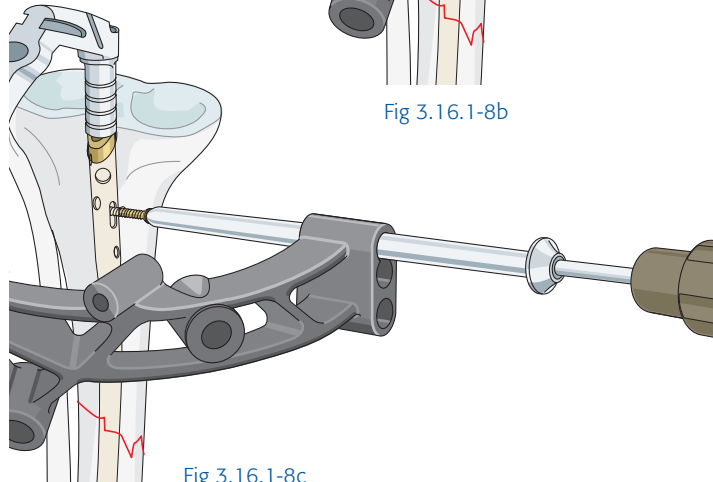
Insertion of end cap

- Remove the aiming arm, connecting screw, and insertion handle.
- Select the appropriate end cap. The size depends on how deep the nail has been inserted into the tibia. After insertion of the end cap, it should be flushed with the surface of the bone.
- Inserting the end cap may be difficult especially if the nail is deeply buried in the bone. Tie an absorbable suture around the neck of the end cap and leave the ends long. Holding the long ends against the screwdriver handle provides greater stability at the screwdriver/end cap interface. It also allows easy retrieval of the end cap from the wound if it comes off the screwdriver.
- Flex the knee fully to obtain a good view and insert and tighten the end cap with the screwdriver.
- Take final x-rays to ensure that all locking screws are correctly inserted and the fracture is well aligned.
- Close the wound.

Further information is available on AO Teaching video 00130: Tibia Fractures—Intramedullary Nailing With the Expert Tibial Nail (With Reaming); video 00131: Tibia Fractures—Intramedullary Nailing With the Expert Tibial Nail (Without Reaming).

9   Specific perioperative care

- Be prepared for the set-up to require calcaneal traction.
- Be careful with pressure areas, particularly when using a fracture table and in elderly patients.
- If a fracture table is used, confirm that the patient is secured on the table.
- Maintain sterility as the image intensifier is rotated around the surgical field.
- Take special care to maintain sterility when using the long-reaming rod and reamer.
- Check the correct size of definitive implants.

10   Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the implant, unless adequate hard copies have been taken from the image intensifier.
- Watch out for development of compartment syndrome in the first 24 hours after surgery.
- Most patients will be allowed to immediately bear as much weight as is comfortable. However, full weight bearing is not recommended on the 8 mm and 9 mm unreamed nails until there are signs of callus formation.
- Check soft-tissue conditions before the patient is discharged.
- In the elderly, rehabilitation may be limited by other medical conditions.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- If using a traction table ensure that equipment is available for the insertion of a calcaneal pin.
- Check that the full range of instruments and implants are available.
- Be prepared to remove an external fixator.
- The large distractor may be used.
- Have two identical length reaming rods available for intramedullary nail length measurement.
- Have handreamers available (just in case).
- Check the color code for each of the drill bits, sleeves, and screws and their sequence of use.
- Confirm the agreed measurement for the reamer heads, nail, and screws with the surgeon.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Carry out adequate preoperative planning and communicate the plan to the ORP. Specifically identify whether a fracture table is used and if not what other aids to reduction, such as a femoral distractor, will be required. Decide whether to use reaming and inform the ORP of the estimated nail diameter and length.
- Good patient set-up and fracture reduction is essential when using the traction table. It should be achieved before skin disinfecting and draping.
- If a distractor or external fixator is used, the position of the Schanz screws should not interfere with the future position of the nail.
- Getting the correct entry point for the nail in the proximal tibia is crucial and must be checked with the image intensifier.
- Correct distal reaming rod placement in both planes is important and must be checked with the image intensifier before reaming.
- Reaming must be done in a gentle, progressive manner without excessive force to limit damage to the cortical blood supply.
- Check the passage of the nail across the fracture site with the image intensifier to avoid further fractures and malalignment.
- Check that the reaming rod has been removed from the nail before starting the locking procedure.
- When using distal locking ensures that the C-arm is in the correct position before drilling. The image intensifier should show a perfectly round hole if the x-ray beam is directly in line with the plane of the hole in the nail.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Paulo Barbosa

3.16.2   Diaphyseal open tibial fracture (42-B1): stabilization with large external fixator

Surgical management

- Application of modular large external fixator in open tibial shaft fracture

Alternative implants

- Expert tibial nail
- Universal tibial nail
- LCP 4.5/5.0 narrow
- LC-DCP 4.5 narrow
- DCP 4.5 narrow

1   Introduction
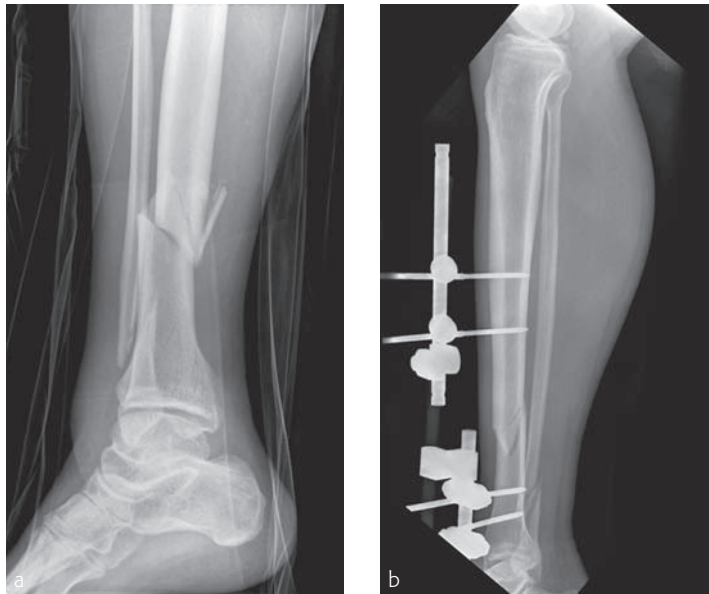
Fig 3.16.2-1a–b
a   Preoperative x-ray: open fracture of distal third of tibia.
b   Postoperative x-ray: stabilization with large external fixator.

- Emergency tibial external fixation is the management of choice for:
  – Gustilo IIIb and IIIc open fractures
  – Open fracture when the surgical expertise in internal fixation is limited
  – Severely injured patients (ISS >25) with long-bone fractures when a damage-control strategy is being applied
- In closed fractures external fixators may be indicated if the general circumstances or the resources do not permit use of internal fixation techniques. A clear understanding of the technique is, however, necessary.
- An external fixator can be applied before or after fracture reduction.

- Reducing the fracture before applying the fixator allows all pins to be lined up with one or two bars to connect them across the fracture site (Fig 3.16.2-2). This technique is more demanding than applying the fixator before fracture reduction (as described below), and has the disadvantage of limited potential for secondary axial alignment. However, once completed, it provides a stronger construct.
- The modular technique in open fractures has the considerable advantage that the Schanz screws can be placed away from the traumatic wound and outside the zone of injury, which reduces the risk of infection. Soft-tissue management/cover is usually done after stabilization of the bone but it must be planned, especially if the wound cover requires a plastic procedure.
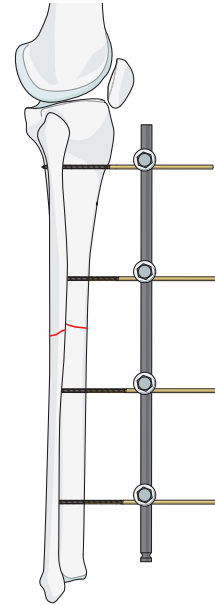
Fig 3.16.2-2

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues (open, Gustilo grade, compartment syndrome)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Large external fixator set
- General orthopaedic instruments set
- Compatible air or battery drill with attachments
- Separate set for debridement
- Large amount of fluids for irrigation

Equipment:
- Standard radiolucent operating table
- Use of a table with split legs may facilitate procedure
- Table and positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient

Author   Paulo Barbosa

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.
- Avoid long-acting regional anesthetics, as they can mask the development of compartment syndrome.

4   Patient and x-ray positioning

- The patient is positioned supine on a radiolucent table (Fig 3.16.2-3).
- Place a sandbag under the buttock of the injured side to cause internal rotation of the limb and to facilitate access to the tibia.
- Take great care of soft tissues and skin pressure points.
- Place the image intensifier on the opposite side of the injured limb.
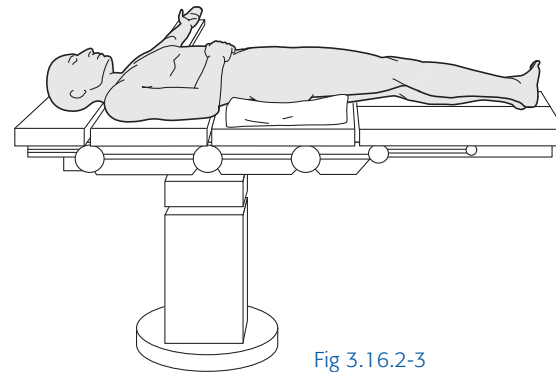
Fig 3.16.2-3

5 Skin disinfecting and draping

- Limb with open, contaminated wounds require thorough precleaning before the disinfecting procedure; if possible in the preparation room, outside the operating room.
- Use an aqueous antiseptic.
- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the exposed area from the hip including the foot with the appropriate antiseptic (Fig 3.16.2-4a).

- Drape the limb with a single-use U-drape or extremity drape. Use a sterile glove to cover just the forefoot leaving the ankle exposed.
- Drape the leg so as to allow it to be moved freely (Fig 3.16.2-4b).
- Drape the image intensifier.
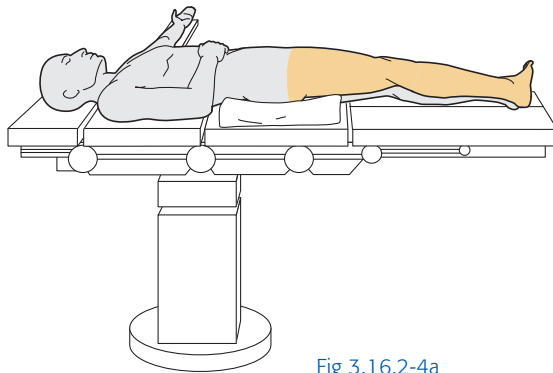
Fig 3.16.2-4a

Fig 3.16.2-4b

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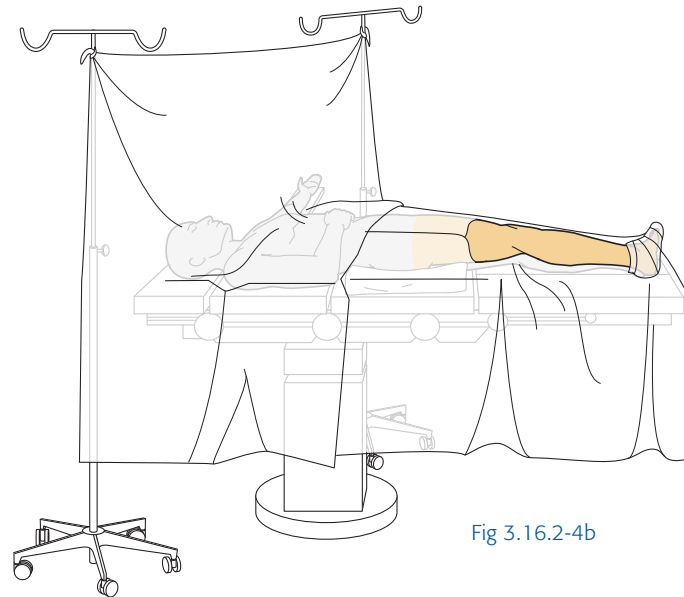
6   Operating room set-up

- The ORP and the surgeon stand on the side of the injury.
- The assistant is at the end of the table where he/she can control the foot.
- Position the image intensifier on the side opposite the injury.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.16.2-5).
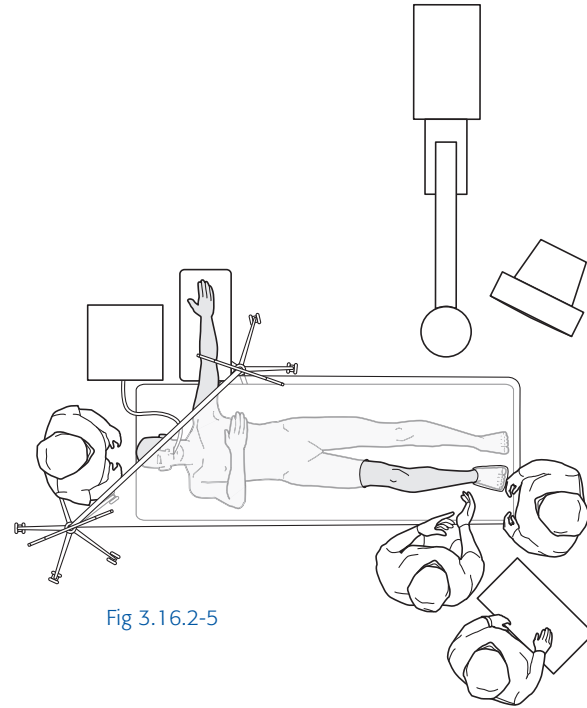
Fig 3.16.2-5

7 Instrumentation
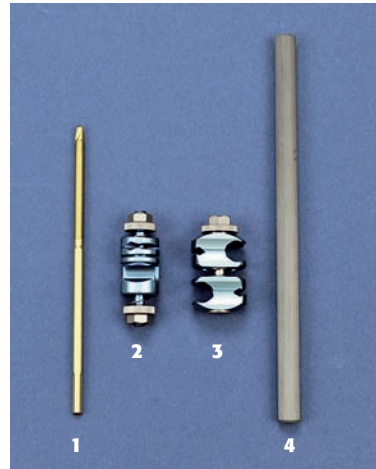
Fig 3.16.2-6a   Implants
1.   Seldrill Schanz screw 5.0 mm
2.   Self-holding clamp
3.   Self-holding combination clamp
4.   Carbon fiber rod 11 mm
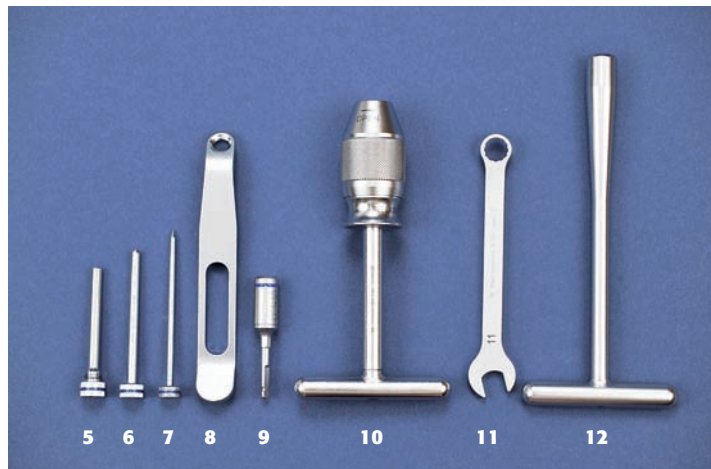
Fig 3.16.2-6b   Instruments for fracture fixation with external fixator
5–8. Triple drill sleeve assembly (drill sleeve 6.0/5.0 mm, drill sleeve 5.0/3.5 mm, trocar 3.5 mm and handle)
9.   Adapter for Schanz screws 5.0 mm
10.   Universal chuck with T-handle
11.   Combination wrench 11 mm
12.   Socket wrench 11 mm

Author   Paulo Barbosa

8   Procedure and technique—step-by-step

- Open fractures must be thoroughly washed out and debrided of all contaminated or necrotic tissue with large volumes of saline.
- If the contamination is substantial, disinfection and new drapes and another set of instruments may be necessary before surgery to apply the external fixator.
- Plan the placement of the Schanz screws, at least two in each main fragment, preferably in the anteromedial aspect of the tibia, but more important through healthy tissue and as far apart from each other as possible.
- Take note of future plastic surgical procedures that may be necessary when planning pin placement.
- Make a stab incision down to the bone.
- Insert the short drill sleeve assembly (handle, drill sleeves 5.0/3.5, and trocar) through the incision down to the bone and hold it perpendicular to the bone.
- Mount a 5 mm Seldrill Schanz screw in the Seldrill adapter and couple it to the power drill.
- Remove the trocar and the 3.5 drill sleeve and insert the Schanz screw through the 5.0 drill sleeve into the bone. The Schanz screw should pass through the near cortex while the tip should come to rest in the far cortex (Fig 3.16.2-7a).
- The tip of the Seldrill Schanz screw should not penetrate the far cortex completely (be careful: sharp drill tip).
- It can be difficult to determine the correct moment to stop drilling. It is recommended that the power drill is exchanged for the universal chuck and the Seldrill Schanz screw advanced by hand once the near cortex has been penetrated and the threads have engaged.
- Check that the position is correct using the image intensifier.
- Option: conventional self-tapping Schanz screws can be used but must be predrilled through both cortices using a 3.5 mm drill bit with the same drill sleeve assembly. They should engage the opposite cortex fully.

- Using the same technique, insert two Seldrill or conventional Schanz screws in each main fragment as far apart as possible (Fig 3.16.2-7b).
- Connect each pair of Schanz screws proximally and distally with an 11 mm carbon fiber (or stainless steel) rod, using conventional or clip-on clamps thereby creating two pairs of "handles." Each rod should protrude sufficiently beyond the clamp on the side of the fracture to allow addition of a combination (rod-to-rod) clamp (Fig 3.16.2-7c).
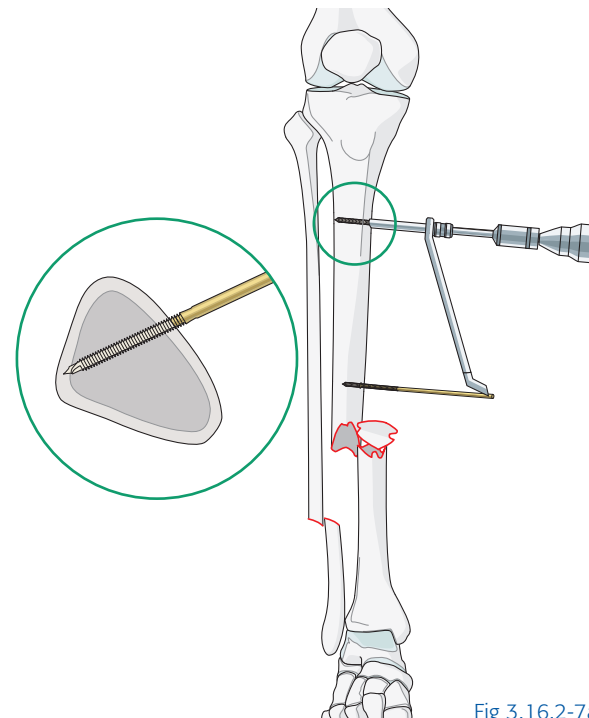
Fig 3.16.2-7a

- Tighten the nuts of all clamps. The two handles can now be used to manipulate the fracture.
- Place on each protruding bar a self-holding combination clamp and connect the two handles with a third short rod, creating a three-rod assembly.
- Manipulate the handles to reduce the fracture approximately and tighten the nuts on the combination clamps (Fig 3.16.2-7d).
- Check reduction using the image intensifier and make final adjustments.
- Again tighten all nuts on all clamps.
- Make final imagings to check Schanz screw length and fracture reduction in both planes.
- Release any skin tension around Schanz screws using a scalpel and suture any large incisions. Most surgeons do not advice primary closure of severe open fractures.

Further information is available on AO Teaching videos:
video 00116: Tibia Shaft Fracture—Large External Fixator: Modular Frame.
video 00117: Tibia—Shaft Fracture (42-A1)—Large External Fixator: Multi-pin Clamp Frame.
video 00118: Tibia Shaft Fracture—Large External Fixator: Uniplanar Double-rod Frame.
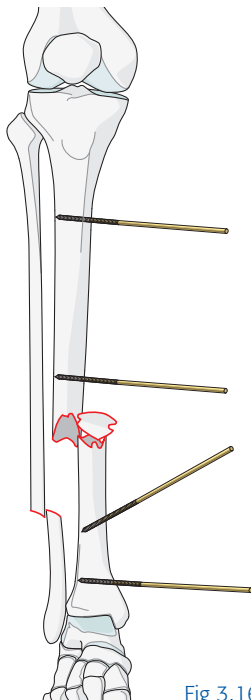
Fig 3.16.2-7b
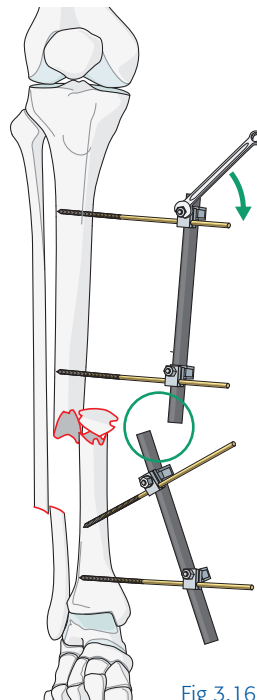
Fig 3.16.2-7c

Fig 3.16.2-7d

Author   Paulo Barbosa
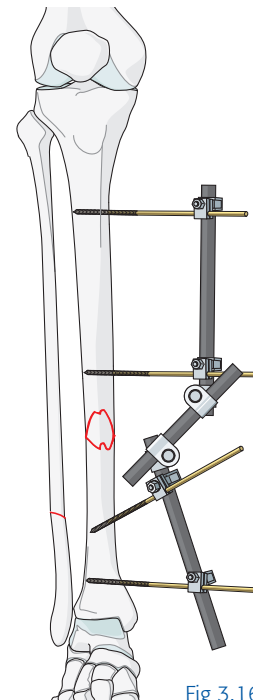
9   Specific perioperative care

- Take particular care to perform adequate decontamination and debridement of any open wounds.
- Be careful with pressure areas, especially in elderly patients.
- Maintain sterility as the image intensifier is rotated around the surgical field.

10   Specific postoperative care

- X-rays should be taken postoperatively to check and document the reduction and position of the Schanz screws, unless saved image intensifier views are adequate.
- The limb must be placed in an elevated position to reduce soft-tissue swelling.
- Monitor the patient for symptoms and signs of compartment syndrome. Be aware that compartment syndrome can occur in open fractures.
- Careful pin-track care is crucial to prevent infection. Initially, the pin sites must be cleaned and dressed daily.
- Generally, open fracture wounds that have been left open need inspection and redebridement and/or secondary skin cover within 48 hours.
- Plan definite internal fixation within 7–10 days at the latest.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Prepare irrigation and debridement set.
- Check that the full range of implants and instruments are available.
- Make sure external fixator clamps are not damaged and are correctly assembled.
- Check that there is a selection of 11 mm carbon fiber (or stainless steel) rods of appropriate length, and Seldrill or conventional Schanz screws are available.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Debridement and irrigation of any open wound must be thorough. A minimum of 5 liters must be used. The patient may need to return to the operating room 48 hours later for a second look and further debridement.
- Plan the Schanz screws placement well away from the traumatic wound, wide apart, and not interfering with any subsequent orthopaedic or plastic surgery.
- Modular rod-to-rod fixators can be manipulated again at a later date, without anesthesia, to correct any malalignment.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.17   Distal tibial fractures

Author   Fabio Castelli

3.17   Distal tibial fractures

Implants and surgical technique

- LCP distal tibia plate 3.5 medial and 3.5 mm cortex screw as lag screw using minimally invasive technique (MIPO)
- Large external fixator spanning the ankle joint
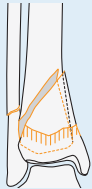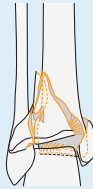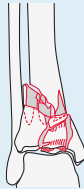
Cases

- Distal tibial fracture (43-A1)
- Pilon tibial fracture (43-C2)

Introduction

- The Müller AO/OTA Classification divides distal tibial fractures in three groups:
  - type 43-A: extraarticular fracture
  - type 43-B: partial articular fracture
  - type 43-C: complete articular fracture
- The medial border of the tibia has no muscle coverings and lies directly beneath the skin. Open fractures are therefore common.
- The distal third of the tibia and fibula have no muscle attachments. Periosteal blood supply is therefore poor and fractures may easily devitalize areas of the bone.
- The blood supply to the skin in this area is also poor, especially in patients with diabetes and smokers. High-energy trauma produces severe damage to the soft tissues even in closed injuries. Immediate surgery to damaged soft tissues may render them avascular, leading to wound breakdown and infection.
- The blood supply to the lower leg is provided by three arteries. It is delicate and vulnerable and depends on the patency of these vessels that are often obstructed in the elderly patient.
- Low-energy trauma usually leads to simple fracture patterns with little soft-tissue injury.

- High-energy trauma with axial compression produces complex articular impaction, metaphyseal comminution, bone loss, and associated contused or crushed soft tissues with or without an open injury.
- Timing of surgery and choice of procedure is determined by the soft-tissue conditions.
- Simple fractures with minimal soft-tissue injury may be stabilized by ORIF within the first 6–8 hours.
- For more complex fractures, and in case of doubtful soft-tissue conditions, staged procedures are recommended as follows:
  - Closed reduction and application of a temporary bridging external fixator (calcaneus to tibia shaft), with or without stabilization of the fibula
  - Elevation of the leg to allow swelling to settle and soft-tissue recovery
  - Perform definitive internal fixation once soft tissues have healed
- For most complex intraarticular fractures it is preferable to delay surgery until soft tissues have settled. This usually takes 7–14 days but occasionally longer.
- Techniques for fixing high-energy pilon fractures are variable and depend on the exact fracture pattern. They are not described in this book.

659

Müller AO/OTA Classification—distal tibia

| 43-A1 | 43-A2 | 43-A3 | 43-B1 | 43-B2 | 43-B3 | 43-C1 | 43-C2 | 43-C3 |

43-A   extraarticular fracture
43-A1   simple
43-A2   wedge
43-A3   complex

43-B   partial articular fracture
43-B1   pure split
43-B2   split-depression
43-B3   multifragmentary depression

43-C   complete articular fracture
43-C1   articular simple, metaphyseal simple
43-C2   articular simple, metaphyseal multifragmentary
43-C3   articular multifragmentary

Author   Fabio Castelli

3.17.1   Distal tibial fracture (43-A1): stabilization with LCP distal tibia plate 3.5

Surgical management

- Stabilization with 3.5 mm cortex screw as lag screw and LCP distal tibia plate 3.5 medial using minimally invasive technique (MIPO)

Alternative implants

- 3.5 mm cortex screw as lag screw and LCP metaphyseal plate 3.5
- 4.5 mm cortex screw as lag screw and LC-DCP 4.5
- Expert tibial nail (if fracture site is not too distal)
- Hybrid ring external fixator

1   Introduction
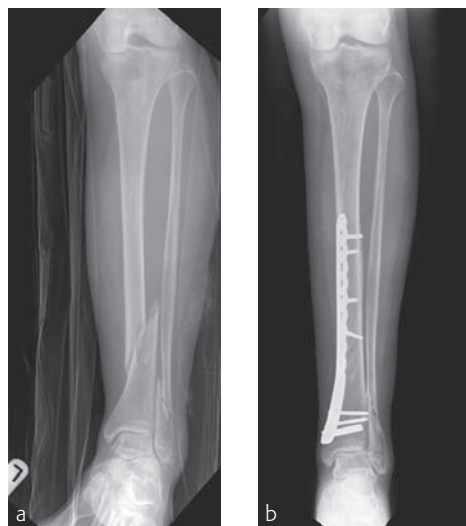
Fig 3.17.1-1a–b
a   Preoperative x-ray: spiral extraarticular distal tibial fracture.
b   Postoperative x-ray: stabilization using LCP distal tibia plate (3.5).

- Fracture type 43-A1 is a simple (oblique) extraarticular fracture of the distal tibia, which may have an associated fibula fracture.
- As the simple type A fracture has only two parts, anatomical reduction and interfragmentary compression with a lag screw is essential. To protect the screw and to ensure stable fixation the application of a plate acting as a protection plate is needed.
- ORIF of the fibula may facilitate reduction and can increase stability.
- Minimally invasive plate osteosynthesis (MIPO) helps to preserve the soft-tissue envelope and reduces the risk of iatrogenic vascular damage at the fracture site.
- The use of an anatomically precontoured plate avoids having to bend the plate and makes its insertion easier.
- The use of locking screws means the plate does not have to be perfectly contoured to the bone and as it is not pressed against the bone surface further damage to the blood supply is avoided.
- In patients with osteoporotic bone a locking plate is favored, since locking head screws (LHS) provide a better purchase in poor-quality bone.
- Careful preoperative planning is crucial.

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2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:

- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used (note: plates come in right and left versions)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:

- Small fragment instrument and 3.5 mm screw sets
- LCP distal tibia plate 2.7/3.5 medial set (note: right or left)
- One-third tubular plates
- General orthopaedics instruments
- Compatible air or battery drill with attachments

Equipment:

- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

Author   Fabio Castelli

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Place the patient in the supine position with elevation of the leg to be operated on. Bend the knee slightly by "breaking" the table (Fig 3.17.1-2a).
- Place a sandbag under the ipsilateral buttock to internally rotate the leg about 15° (Fig 3.17.1-2b).

- Apply a tourniquet proximal to the knee, inflate only if required.
- Ensure that the image intensifier is positioned so as to obtain AP and lateral views by a simple rotation of the C-arm.

Fig 3.17.1-2a

15°
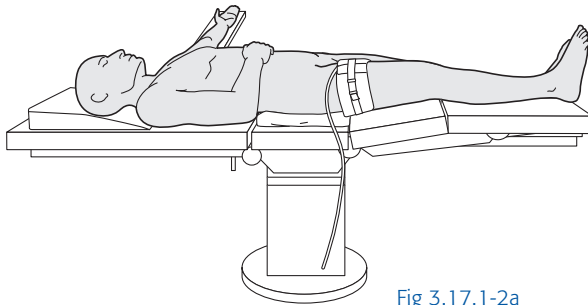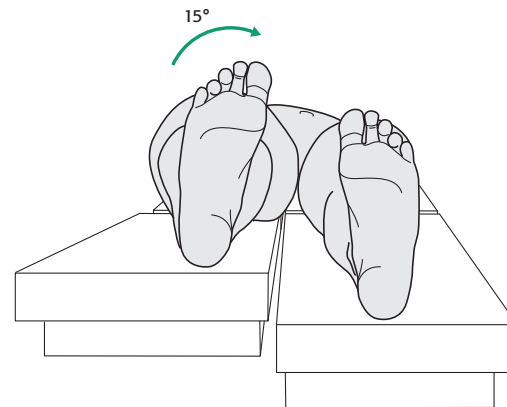
Fig 3.17.1-2b

5 Skin disinfecting and draping

- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the leg from mid thigh to the toes with the appropriate antiseptic, making sure no solution soaks under the tourniquet (Fig 3.17.1-3a).

- Drape the leg with a single-use U-drape or extremity drape. A stockinette fixed with a tape or a glove covers just the forefoot (Fig 3.17.1-3b).
- Rotate the ankle 15° slightly over a sterile roll.
- Drape the image intensifier.
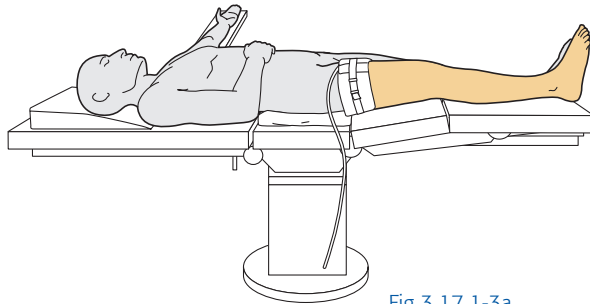
Fig 3.17.1-3a
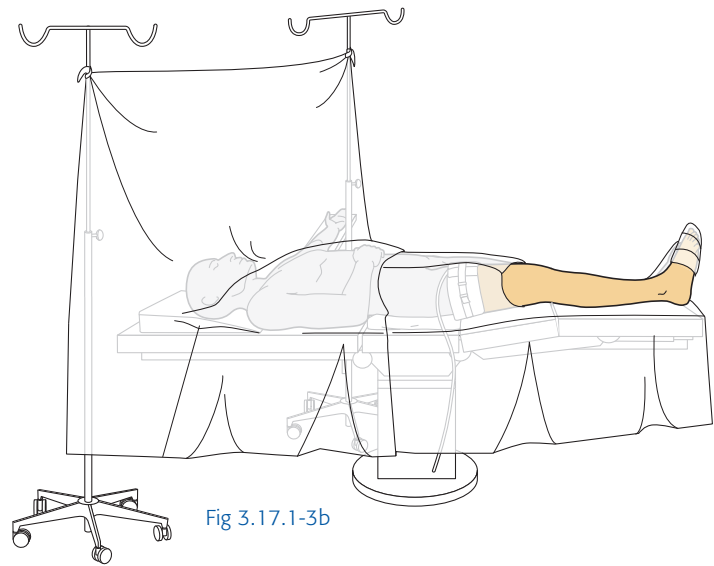
Fig 3.17.1-3b

Author   Fabio Castelli

6   Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- The assistant stands at the foot of the table.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.17.1-4).
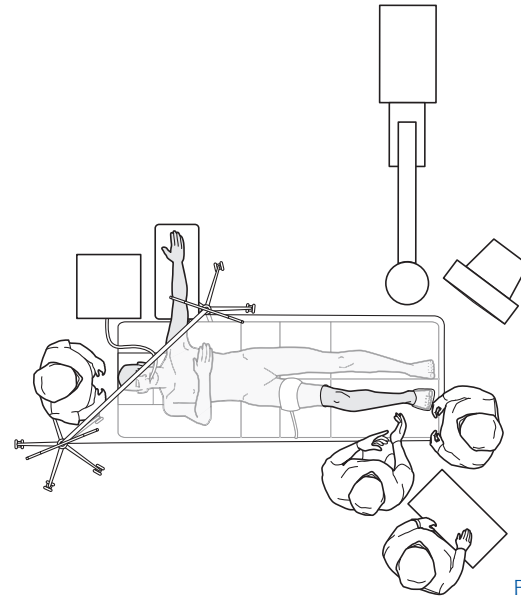
Fig 3.17.1-4

7 Instrumentation
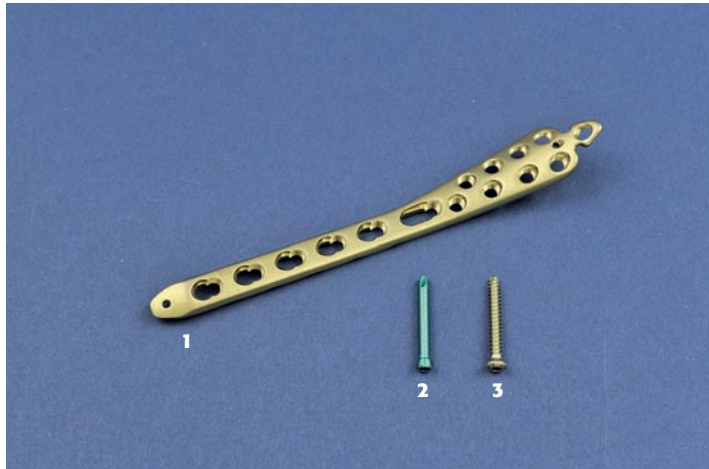
Fig 3-17.1-5a   Implants
1.   LCP distal tibia plate 3.5 mm
2.   Locking head screw 3.5 mm, self-tapping
3.   Cortex screw 3.5 mm
     Note: one-third tubular plate (not in picture)
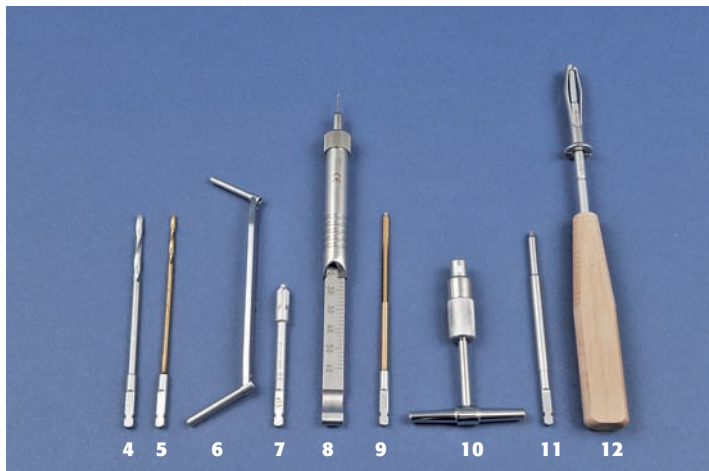
Fig 3-17.1-5b   Instruments for fracture and plate fixation with conventional screws.
4.   Drill bit 3.5 mm
5.   Drill bit 2.5 mm
6.   Double drill sleeve 3.5/2.5 mm
7.   Countersink 3.5 mm
8.   Depth gauge
9.   Tap 3.5 for cortex screws
10. T-handle
11. Screwdriver shaft
12. Screwdriver with holding sleeve

Author   Fabio Castelli
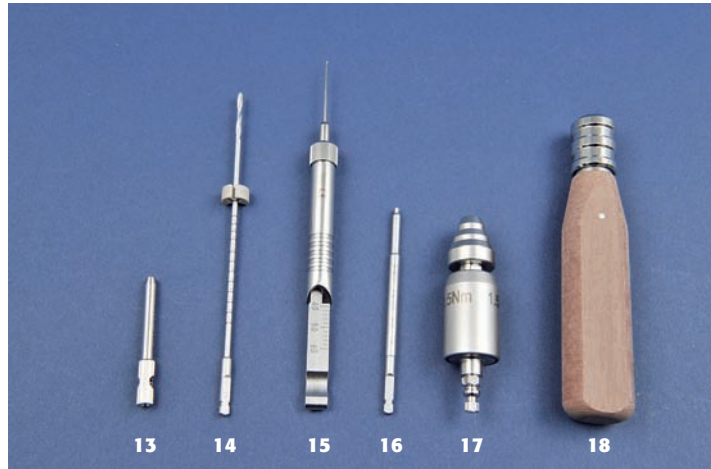
Fig 3-17.1-5c   Instruments for plate fixation with locking head screws
13.   LCP drill sleeve 3.5 mm
14.   Drill bit 2.8 mm
15.   Depth gauge
16.   Screwdriver shaft
17.   Torque limiter 1.5 Nm
18.   Handle for torque limiter

Fig 3-17.1-5d   Instruments for reduction and plate contouring
19.   Reduction forceps with points, small
20.   Reduction forceps with points, large
21.   Bending pin
22.   Bending pliers

8 Procedure and technique—step-by-step

- Reduce and fix the fibula with a one-third tubular plate as a first step. The need for this will depend on the surgeon's preference and the exact pattern of the tibial fracture. The more complex the tibial component the more useful fibula fixation is likely to be. This is not described here.
- Make a straight 4–5 cm skin incision about 1.5 cm lateral to the crest of the tibia at the level of the fracture site.
- Expose the fracture. Remove and wash out the hematoma and debris.
- Do not strip the periosteum other than to view the fracture line.
- Reduce the fracture by gentle manipulation assisted by a pointed reduction forceps, one branch of which may have to be applied through a separate stab incision (Fig 3.17.1-6a).
- Make sure the reduction is anatomically perfect and check it with the image intensifier.

- Choose the best position for insertion of a 3.5 mm cortex screw applied as a lag screw. It should be at a right angle to the fracture plane. Depending on the planned direction, this lag screw can be placed outside the plate or through one of the plate holes.
- Drill the gliding hole with the 3.5 mm drill bit and protection sleeve, followed by the 2.5 mm drill sleeve and 2.5 mm drill bit for the thread hole in the far cortex (Fig 3.17.1-6b).
- Countersink the entry hole and measure the screw length with the small depth gauge.
- Tap the far cortex with the 3.5 mm (gold-color) cortical tap (Fig 3.17.1-6c).
- Insert the fully threaded 3.5 mm cortex screw of appropriate length and tighten it (Fig 3.17.1-6d).
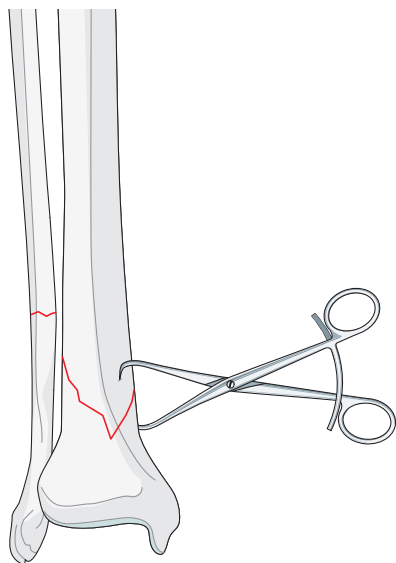
Fig 3.17.1-6a
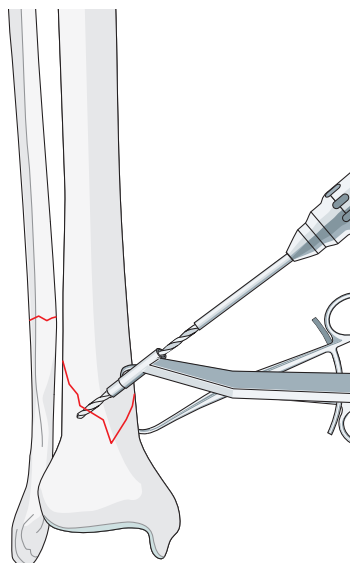
Fig 3.17.1-6b
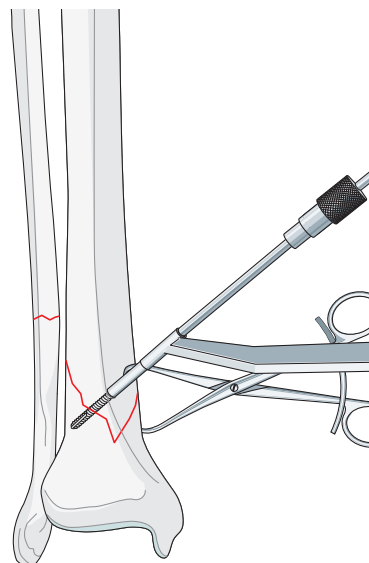
Fig 3.17.1-6c

Fig 3.17.1-6d

Author Fabio Castelli
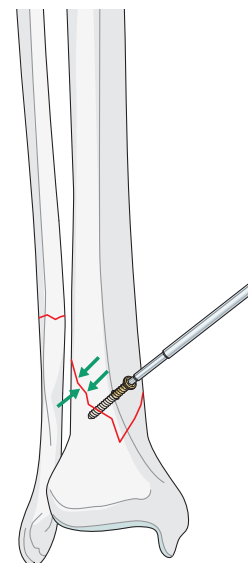
- Make a second 2–3 cm long incision over the medial malleolus, taking care not to injure the saphenous nerve and vein which lie anteriorly.
- Mount the threaded LCP drill sleeve firmly to one of the distal holes of the selected LCP to make an excellent handle to insert the plate subcutaneously.
- Insert the plate epiperiosteally, gliding it along the medial surface of the tibia.
- Identify the proximal end of the plate by palpation and make a short incision there to allow visual control of the correct position of the plate in the center of the medial surface of the bone.
- Fix a second LCP drill sleeve to the most proximal plate hole for easier manipulation.
- Check the final plate position with the image intensifier and fix the plate temporarily at each end with 1.6 mm K-wires through the small holes at each end of the plate (Fig 3.17.1-6e).
- Drill the first distal hole for a lockin head screw (LHS) with a

2.8 mm drill bit through the already mounted drill sleeve (Fig 3.17.1-6f).
- Read the screw length off the calibration on the drill bit or use a depth gauge.
- Insert a 3.5 mm LHS of appropriate length using the power drill. The last few turns must always be done manually with the 1.5 Nm torque limiter mounted on the handle. A "click" signals the screw is secure (Fig 3.17.1-6g).
- Apply a second LHS in the third most proximal plate hole, using the same technique and check the reduction again.
- One more LHS proximally and distally will be sufficient to protect the lag screw and to provide the necessary stability.
- Remove K-wires (Fig 3.17.1-6h).
- Close the wounds.

Further information is available on AO Teaching video 20207: Locking Compression Plate (LCP) Percutaneous Plate Fixation of the Tibia and Fibula in a Distal Multifragmentary Fracture of the Lower Leg (MIPO Technique).
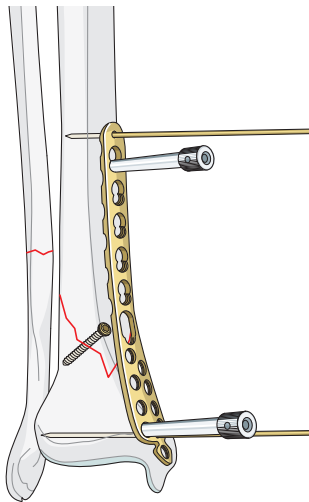
Fig 3.17.1-6e
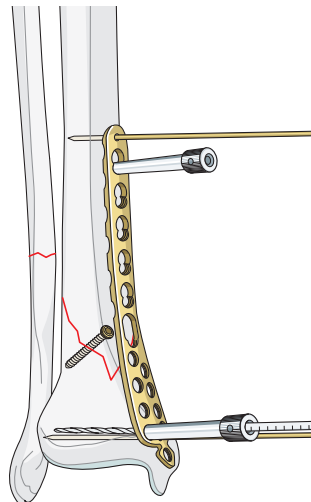
Fig 3.17.1-6f
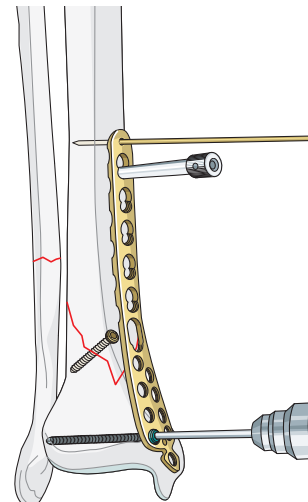
Fig 3.17.1-6g
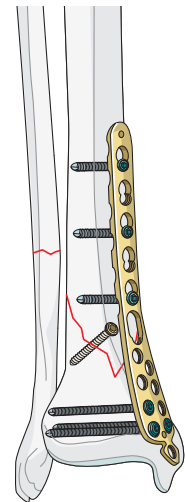
Fig 3.17.1-6h

9 Specific perioperative care

- Check that the patient is properly secured on the radiolucent table.
- Check that a pad is placed under the ipsilateral buttock to internally rotate the leg.
- Take care to protect pressure areas (mainly in the elderly).
- Check tourniquet positioning and that safe tourniquet time is not exceeded, if used.
- Maintain sterility as the image intensifier is rotated around the leg.

10 Specific postoperative care

- Take x-rays postoperatively to check and document the reduction and position of the implants.
- Keep the leg elevated postoperatively. A U-shaped splint may help to prevent the foot developing an equinus position immediately after surgery.
- Start mobilization with a physiotherapist on the first postoperative day and according to the surgeon's instructions.
- Weight bearing (5–10 kg) may be started after 2 weeks, provided the patient is compliant and the fixation stable.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants (note: the plate comes in left and right versions) and instruments are available.

- Note that 2.7 mm LHS could be used for the distal part in the plate.
- Make sure the threads of the LCP drill sleeves are not damaged.
- Always have at least one additional LCP drill sleeve available.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check with x-rays in both planes that an anatomical reduction with correct axial alignment has been achieved and the plate is lying correctly on the bone in both planes before any LHS are inserted through the LCP.
- Make sure the saphenous vein and nerve are not injured at the medial malleolus incision.
- Make sure the LCP drill sleeve is firmly engaged in the threaded part of the combination hole by trying to move it along the long axis of the plate.

- Insert the self-tapping LHS with the power drill and the torque-limiting attachment; however, the last few turns must be done by hand and the torque-limiting attachment must be mounted on a handle. Screws inserted too tight can be difficult or impossible to remove.
- If the tibial fracture is multifragmentary, do not attempt to fix with lag screws but use the tibia plate as a bridging plate. In these cases it is particularly helpful to fix the fibula first to obtain the correct length, and it may be necessary to use more than two LHS on each side of the plate.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Author   Fabio Castelli

3.17.2   Pilon tibial fracture (43-C2): stabilization with large external fixator

Surgical management

- Temporary stabilization with large spanning external fixator in triangular configuration

Alternative implant

- Hybrid ring external fixator

1   Introduction

- Complex type C pilon fractures always have associated soft-tissue injuries which are usually severe. They require immediate stabilization to facilitate soft-tissue healing, but this must be done by external fixation since ORIF will produce additional soft-tissue trauma resulting in wound breakdown and infection.

- These injuries almost always require evaluation by a CT scan. A careful preoperative plan is mandatory.
- A staged procedure is therefore recommended with initial stabilization by a joint-bridging external fixator until soft tissues have recovered sufficiently to allow further surgery. This takes at least 7–14 days.

Fig 3.17.2-1a–c
a   Preoperative x-ray: multifragmentary intraarticular distal tibial fracture (pilon fracture).
b   Preoperative CT scan: showing degree of displacement of articular surface.
c   Postoperative x-ray: initial stabilization using large external fixator.

- Timing of definitive surgery is determined by the condition of soft tissues.
- Reconstruction of the joint should follow the four principles: (1) reconstruction of the fibula (if fractured); (2) reconstruction of the tibial joint block; (3) autogenous cancellous or cortico-cancellous bone graft (if necessary); and (4) support by a tibial buttress plate.

- Open pilon fractures often require soft-tissue reconstruction by a plastic surgeon. After wound debridement the application of the joint-bridging external fixator should be carefully planned, ideally in the presence of the plastic surgeon, to avoid compromising later reconstructive procedures.
- Joint-bridging external fixation may also be indicated as damage-control surgery in polytrauma patients, and in the management of acute and chronic infection.

2 Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of soft tissues (open or close)
- Implant to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Large external fixator set
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Radiolucent operating table
- Positioning accessories to assist with supine position of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3 Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

Author   Fabio Castelli

4   Patient and x-ray positioning

- Place the patient in the supine position on a radiolucent operating table. Elevate the injured leg. Bend at the knee slightly (Fig 3.17.2-2).
- Place a sandbag under the ipsilateral buttock to internally rotate the leg to about 15°.
- Apply a tourniquet to the thigh, to be inflated if required.
- Place the image intensifier on the opposite side to the injured leg.
- Ensure that the image intensifier can obtain AP and lateral views by a simple rotation of the C-arm.
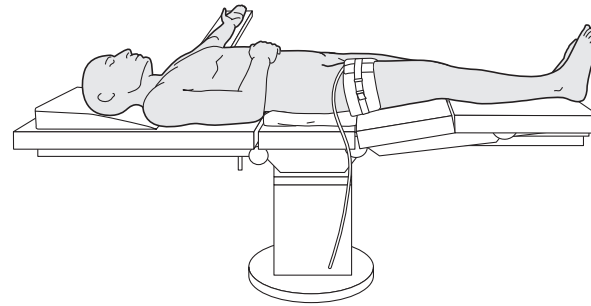
Fig 3.17.2-2

5   Skin disinfecting and draping

- If the fracture is open, preclean the wound with irrigation before draping.
- Maintain light manual traction on the limb during preparation to avoid excessive deformity at the fracture site.
- Disinfect the leg from mid thigh to the toes with an appropriate antiseptic, making sure no solution soaks under the tourniquet (Fig 3.17.1-3a).

- Drape the leg with a single-use U-drape or extremity drape. Toes and forefoot can be covered with a sterile glove (Fig 3.17.1-3b).
- Drape the image intensifier.
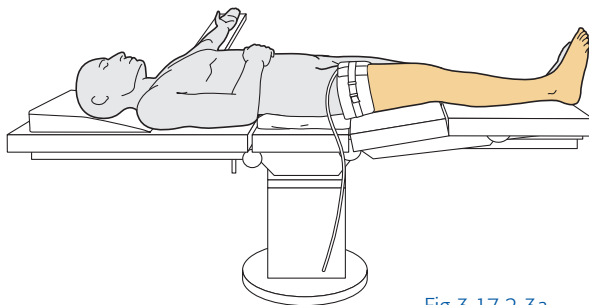
Fig 3.17.2-3a
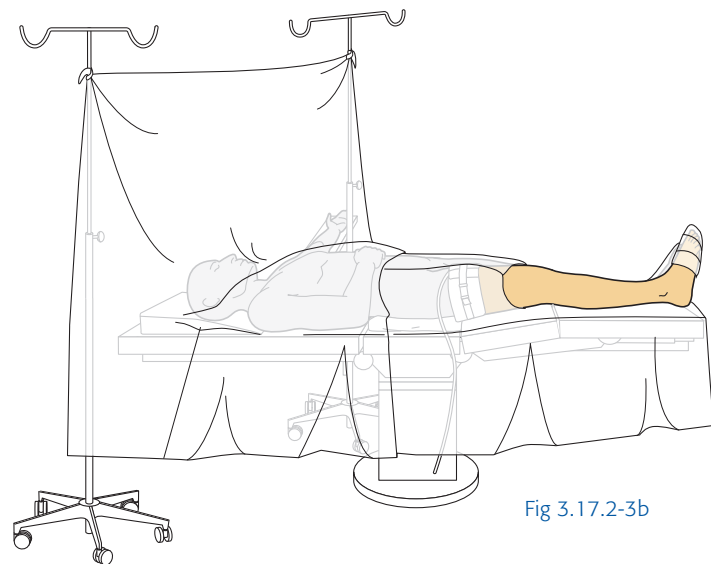
Fig 3.17.2-3b

6 Operating room set-up

- The ORP and surgeons stand on the side of the injury.
- The assistant stands at the foot of the table.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.17.2-4).

Fig 3.17.2-4

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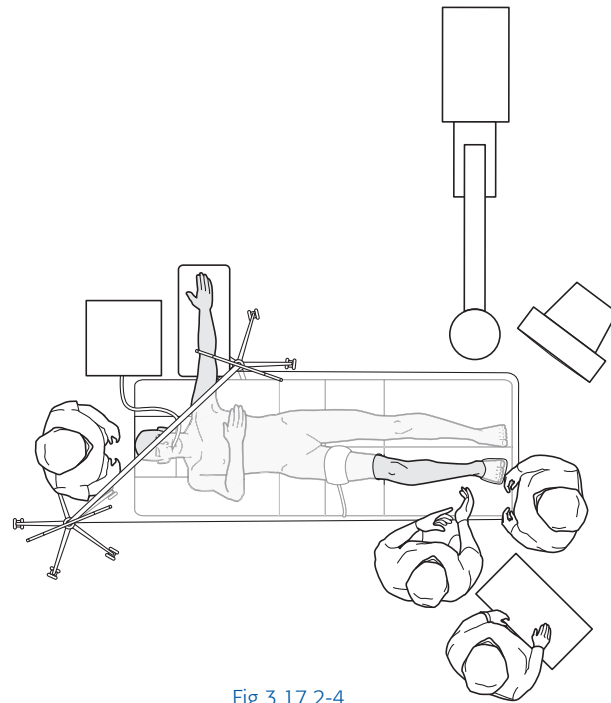
7   Instrumentation
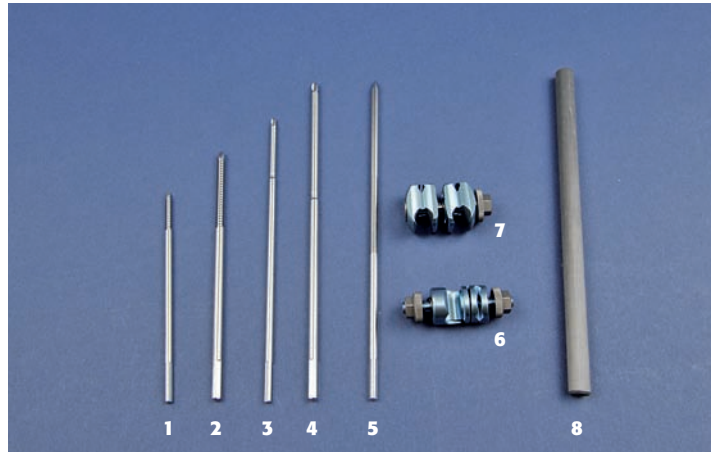
Fig 3.17.2-5a   Implants
1.   Schanz screw 4.0 mm
2.   Schanz screw 5.0 mm
3.   Seldrill Schanz screw 4.0 mm
4.   Seldrill Schanz screw 5.0 mm
5.   Steinmann pin 5.0 mm with middle thread
6.   Self-holding clamp
7.   Combination clamp
8.   Carbon fiber rod 11 mm

Fig 3.17.2-5b   Instruments for large external fixator
9.   Drill bit 2.5 mm
10.   Drill bit 3.5 mm
11.   Triple drill sleeve assembly 4.0 mm
      (drill sleeve 4.0 mm, drill sleeve 4.0/2.5 mm, trocar 2.5 mm)
12.   Triple drill sleeve assembly 5.0 mm
      (drill sleeve 6.0/5.0 mm, drill sleeve 5.0/3.5 mm, trocar 3.5 mm)
13.   Handle
14.   Adapter for Seldrill Schanz screws 4.0 mm
15.   Adapter for Seldrill Schanz screws 5.0 mm
16.   Universal chuck with T-handle
17.   Combination wrench 11 mm
18.   Socket wrench 11 mm

8 Procedure and technique—step-by-step

- Insert the first 5.0 mm Schanz screw at a safe distance from the fracture (outside the zone of injury) and about 1 cm medial to the tibial crest.
- Assemble the short drill sleeve system: handle, drill sleeves 5.0 and 3.5 mm, and trocar.
- Make a stab incision and press the assembled drill sleeves with trocar directly onto the bone (Fig 3.17.2-6a).
- Remove the trocar. If self-drilling and self-tapping 5.0 mm Seldrill Schanz screws are used, the inserted drill sleeve 3.5 mm is also removed.
- Make sure the remaining drill sleeve does not slip when the 5.0 mm Seldrill Schanz screw is inserted.
- Select a Schanz screw of appropriate length.
- Place the Seldrill Schanz screw in the adaptor for the power drive and drill it through the near cortex (Fig 3.17.2-6b). The sharp tip of the Schanz screw should be anchored in the far

cortex without going fully through it. It may be easier to know when this has been achieved by making the last few turns of the Schanz screw by hand using the universal chuck with T-handle.
- Irrigation is always recommended during insertion of the Schanz screws.
- If a conventional threaded 5.0 mm Schanz screw is used, an insertion hole must be drilled with a 3.5 mm drill bit through both cortices.
- Remove the 3.5 mm drill sleeve and measure the length with the depth gauge.
- Mount the 5.0 mm Schanz screw in the universal chuck with T-handle.
- Insert the conventional Schanz screw by hand passing through both cortices.
- Check the position and correct length with the image intensifier.
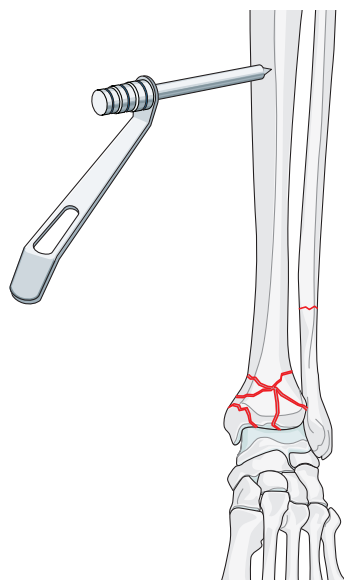
Fig 3.17.2-6a

Fig 3.17.2-6b

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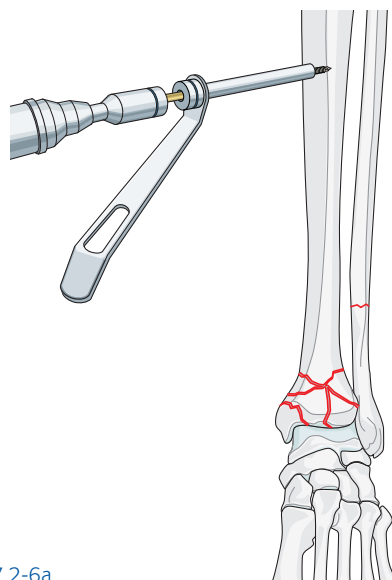
Insertion of Steinmann pin

- Take care not to damage the posterior tibial neurovascular bundle.
- Palpate the e posterior tibial artery which lies posterior to the medial malleolus.
- Make a stab incision over the lateral side of the tuber 2 cm below the artery.
- Prepare a pilot hole with a 3.5 mm drill bit (Fig 3.17.2-6c). Incise the skin medially over the tip of the drill bit as it protrudes through the far side of the hindfoot.
- Mount the 5 mm centrally threaded Steinmann pin on the universal chuck with T-handle and insert it by hand. The threaded segment of the pin should lie within the bone.
- In patients with osteoporotic bone, predrilling a hole before manual pin insertion is not necessary.
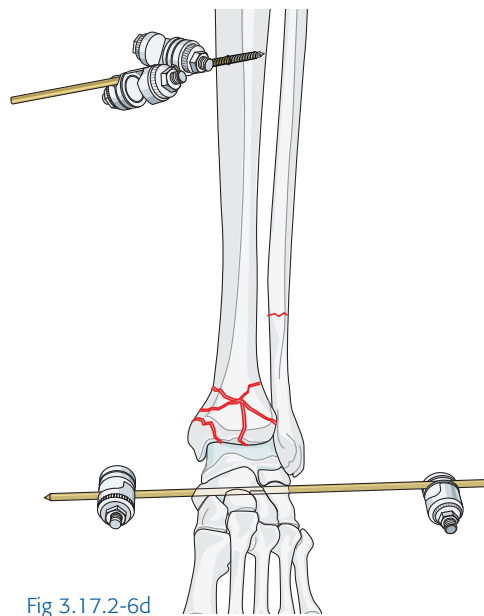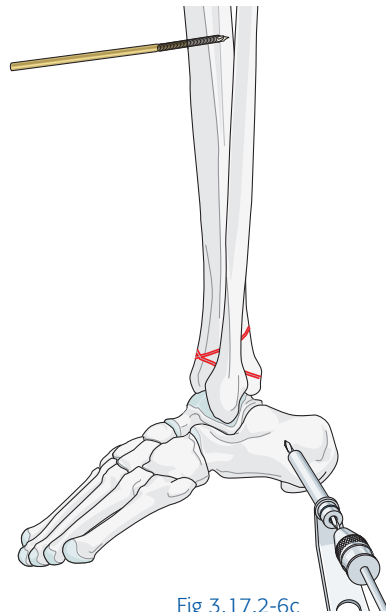
Frame construction

- Mount two self-holding clamps on the Schanz screw in the tibia and one on either side of the Steinmann pin in the calcaneus (Fig 3.17.2-6d).
- Use MR-safe clamps if available, as they do not cause artifact if a magnetic resonance imaging scan is subsequently required.
- Place 11 mm carbon fiber rods medially and laterally through both clamps (Fig 3.17.2-6e).
- Tighten the nuts by hand.
- Reduce the fracture by ligamentotaxis under image intensifier control, manipulating the Steinmann pin in the calcaneus.
- Use the socket wrench to fully tighten nuts on the clamps once satisfactory alignment has been obtained.
- Attach an additional clamp to the medial carbon fiber rod to insert a second Schanz screw into the tibia distal to the first one.

Fig 3.17.2-6c

Fig 3.17.2-6d

Fig 3.17.2-6e
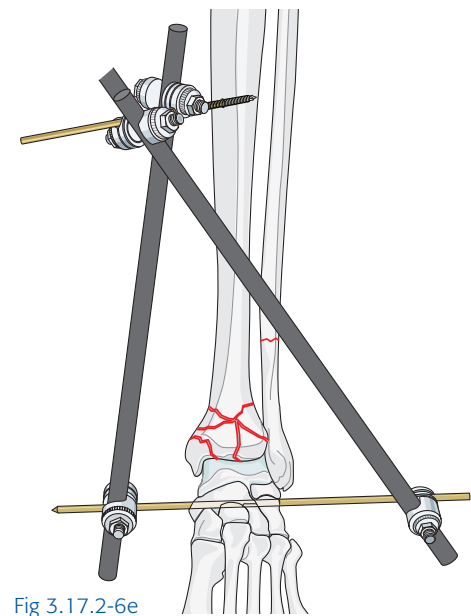
- Mount the drill sleeve assembly into the clamp as a guide and make a stab incision at the tip of the trocar.
- Insert the second 5.0 mm Schanz screw in the same way as the first one to reinforce the fixation to the tibia.
- To prevent an equinus deformity of the foot: introduce a 4 mm Schanz screw into the base of the fifth and/or first metatarsal and connect it to the lateral carbon fiber rod using an additional clamp. It may need predrilling with a 2.5 mm drill bit (Fig 3.17.2-6f).
- Check that every nut on the frame is carefully tightened.

Further information is available on AO Teaching videos:

Video 20160: Pilon Tibial Fractures (Foamed Foot).

Video 00119: Tibia—Intraarticular Fracture—Large External Fixator: Ankle-bridging Delta Frame.

Video 00127: Tibia—Intraarticular Fracture—Large External Fixator: Ankle-bridging Frame with Multi-pin Clamps.
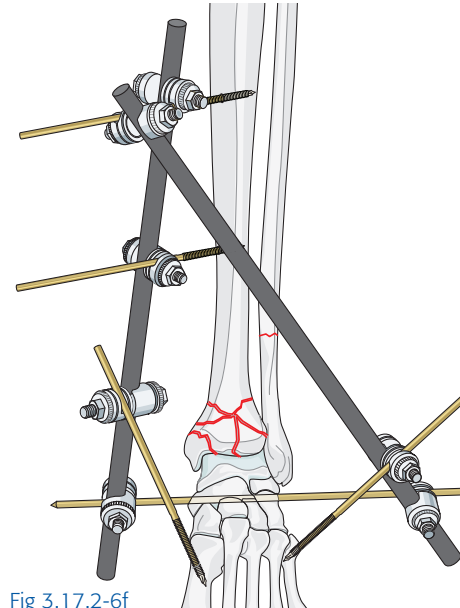
Fig 3.17.2-6f

9   Specific perioperative care

- Make sure that the patient is secured on the radiolucent table.
- Check that a pad is placed under the ipsilateral buttock to internally rotate the leg.
- Take care to protect pressure areas (especially in the elderly).
- Maintain sterility as the image intensifier is rotated around the leg.

Author   Fabio Castelli

10 Specific postoperative care

- Take x-rays postoperatively to check and document the reduction and position of the Schanz screws.
- Elevate the limb to help reduce soft-tissue swelling.
- Monitor the soft-tissue condition and take proper care of the pin tracks with daily cleaning and dressing renewal.

- Delay definitive surgery until soft tissues have recovered (7–21 days).
- Continuous passive motion of the knee may be an option and should be started immediately after surgery.

11 ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Have an additional debridement set and irrigation available (scalpel blades).

- Distinguish between conventional and Seldrill Schanz screws.
- Make sure that all clamps are functioning and are correctly assembled.
- Document and reorder all implants used.

12 Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check patient set-up before surgery.
- Ensure Schanz screws are placed well away from the site of any subsequent definitive fixation or plastic surgery procedure.
- Do not insert conventional Schanz screws in the tibia without predrilling a pilot hole.
- Ensure the first tibial Schanz screw is inserted sufficiently proximally to allow space for the second more distal one to be inserted and remain outside the zone of the injury.
- Incorporation of the mid foot into the frame prevents the development of an equinus or mid-foot pronation deformity and also prevents subluxation of the talus.

- Hemorrhagic blister are more serious than nonhemorrhagic ones and might be a sign of underlying full-thickness skin necrosis. This should lead to an adaptation of the surgical approach.
- If the fracture is open, a second look for further debridement is required.
- Obtain good x-rays in both planes, and usually a CT scan for planning the definitive fixation.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.18   Malleolar fractures

Author   Rodrigo Pesantez

3.18   Malleolar fractures

Case

Trimalleolar ankle fracture (44-B3):
- Lateral malleolus: stabilization with one-third tubular plate and 3.5 mm cortex screws
- Medial malleolus: stabilization with 4.0 mm cancellous bone screws
- Posterior malleolus (Volkmann triangle): stabilization with 4.0 mm cannulated screws

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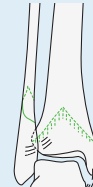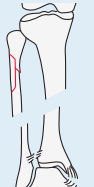
Introduction

According to the Müller AO/OTA Classification, malleolar fractures are divided in:
- Infrasyndesmotic injuries: 44-A (supinated foot, adduction of talus)
- Transsyndesmotic injuries: 44-B (supinated foot, inversion causing external rotation of talus)
- Suprasyndesmotic injuries: 44-C (pronated foot, external rotation of talus)

- Understanding the mechanism of injury and the subsequent pattern of the bony and ligamentous injuries is important in the decision-making process.
- Malleolar fractures are articular injuries which are, unless undisplaced and therefore stable, nearly always an indication for operative reconstruction and fixation. Because of the delicate soft-tissue cover on the two malleoli, timing of surgery is crucial in achieving uneventful healing. In closed fractures, surgery should be performed either within 4–6 hours or after a few days' delay.

Müller AO/OTA Classification—44 malleolar segment

| 44-A1 | 44-A2 | 44-A3 | 44-B1 | 44-B2 | 44-B3 | 44-C1 | 44-C2 | 44-C3 |

44-A   infrasyndesmotic fibular lesion
44-A1   isolated
44-A2   with fractured medial malleolus
44-A3   with posteromedial fracture

44-B   transsyndesmotic fibular fracture
44-B1   isolated
44-B2   with medial lesion
44-B3   with medial lesion and Volkmann
        fracture of the posterolateral rim

44-C   suprasyndesmotic lesion
44-C1   fibular diaphyseal fracture, simple
44-C2   fibular diaphyseal fracture, multifragmentary
44-C3   proximal fibular lesion

Author   Rodrigo Pesantez

3.18.1   Trimalleolar ankle fracture (44-B3):

Lateral malleolus: stabilization with one-third tubular plate
Medial malleolus: stabilization with 4.0 mm cancellous bone screws
Posterior malleolus (Volkmann triangle): stabilization with 4.0 mm cannulated screw

Surgical management

- Lateral malleolus: stabilization with one-third tubular plate and 3.5 mm cortex screw used as lag screw
- Medial malleolus: stabilization with 4.0 mm cancellous bone screws
- Posterior malleolus (Volkmann triangle): stabilization with 4.0 mm cannulated screw

Alternative implants

- Medial malleolus
  – Tension band wiring
- Lateral malleolus
  – LCP one-third tubular plate 3.5

1   Introduction
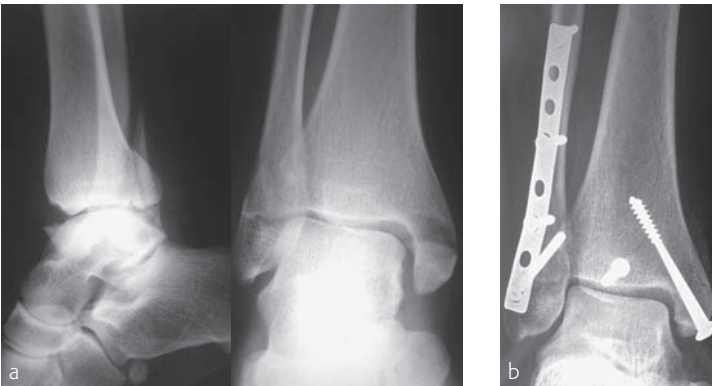
Fig 3.18-1a–b
a   Preoperative x-rays: trimalleolar fracture of the ankle.
b   Postoperative x-ray: stabilization with lag screw and one-third tubular plate (fibula) with medial malleolus—4.0 mm cancellous bone screws; and with posterior malleolus—4.0 mm cannulated screw.

A trimalleolar fracture, Müller AO/OTA Classification 44-B3 (Weber type B), occurs as a result of axial loading of a supinated foot. The talus externally rotates in the mortise and the shearing force to the distal end of the fibula produces an oblique fracture starting at the level of the ankle joint and extending proximally from anterior to posterior. Progressive external rotation causes posterior displacement and a fracture of the posterior malleolus (Volkmann triangle). Finally, as the talus subluxes posteriorly the medial side comes under tension resulting in an avulsion fracture of the medial malleolus (Fig 3.18-2).
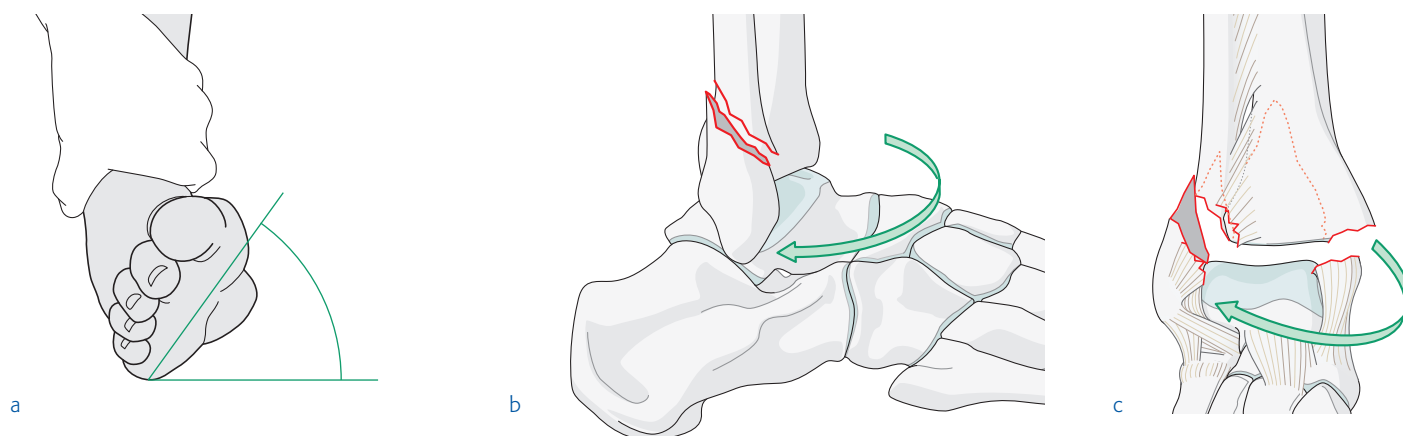
Fig 3.18-2a–c
a–b The ankle inversion (supination) produces external rotation of the talus causing a fracture of the distal fibula.
c   If talar rotation continues, the medial malleous is avulsed.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:

- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implants to be used
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:

- Small fragment set (3.5/4.0 mm)
- K-wires set (1.6–2.0 mm)
- Tension band wiring set (optional)
- Cannulated screw set 4.0 mm
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:

- Radiolucent operating table
- Positioning accessories to assist with supine positioning of the patient (sandbag or cushion)
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

3   Anesthesia

- This procedure is performed with the patient under regional or general anesthesia.

Author   Rodrigo Pesantez

4   Patient and x-ray positioning

- Place the patient supine on a radiolucent operating table (Fig 3.18-3).
- Put a sandbag under the ipsilateral buttock to internally rotate the limb.
- Tilt the table away from the injured side to further increase internal rotation.
- Apply a tourniquet to the femur of the affected side, but inflate it only if required.
- Position the image intensifier and screen on the opposite side from the injured leg.
- Check AP and lateral views before draping the patient.
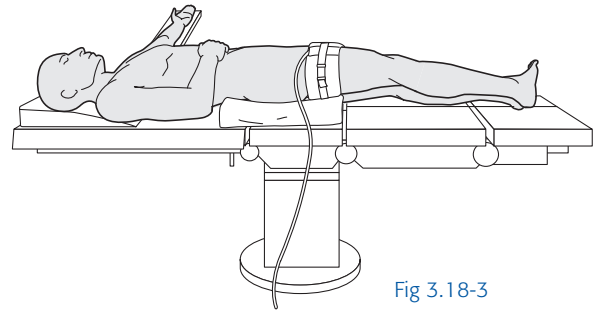
Fig 3.18-3

5   Skin disinfecting and draping

- Disinfect the exposed area of the limb from the foot to the middle of the thigh with the appropriate antiseptic (Fig 3.18-4a).
- Use a single-use waterproof drape, followed by a limb drape (Fig 3.18-4b).
- Isolate the foot with a sterile glove or stockinette.
- A sterile bump helps to maintain the foot in different positions during surgery.
- Drape the image intensifier.
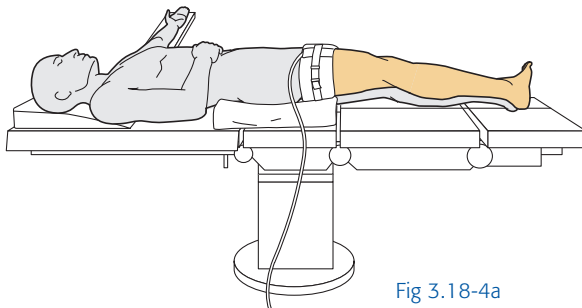
Fig 3.18-4a
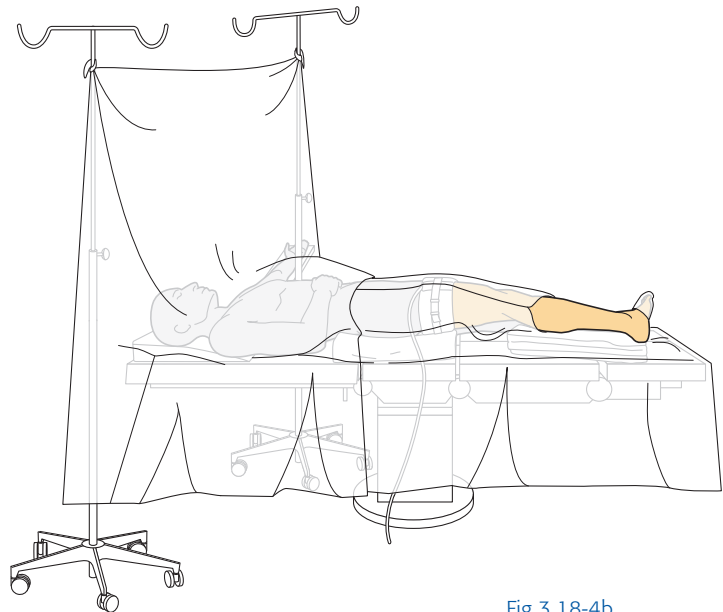
Fig 3.18-4b

6 Operating room set-up

- The surgeon stands or sits on the side of the injury.
- The assistant stands at the foot of the table.
- The ORP stands next to the surgeon.
- The image intensifier is brought in from the foot of the OR table for lateral and axial images.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.18-5).
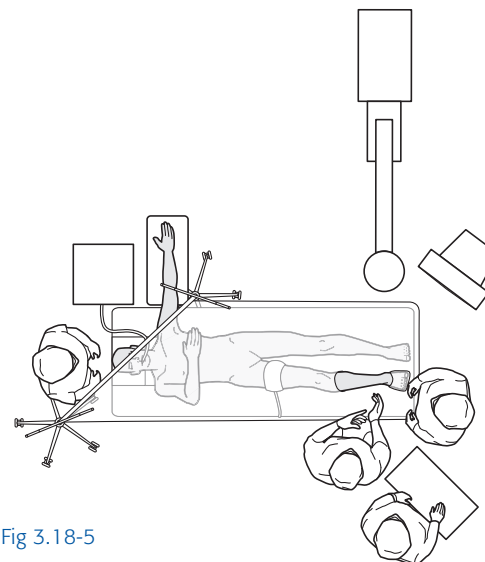
Fig 3.18-5

7 Instrumentation
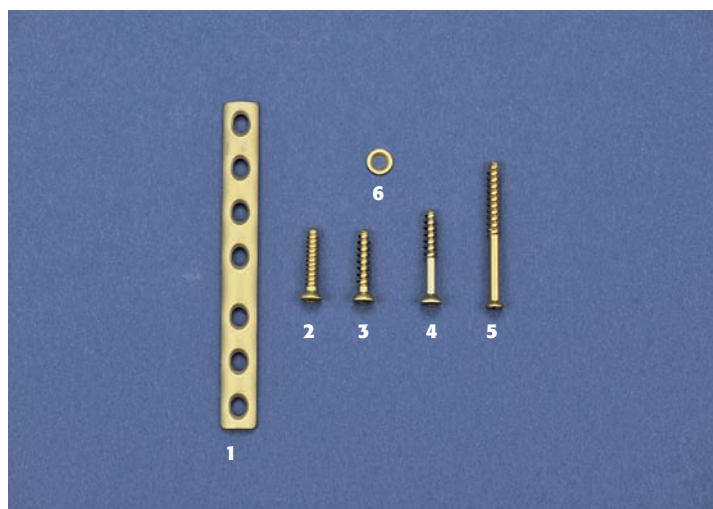
Fig 3.18-6a   Implants
1.   One-third tubular plate 3.5 mm, 7 holes
2.   Cortex screw 3.5 mm
3.   Cancellous bone screw 4.0 mm, fully threaded
4.   Cancellous bone screw 4.0 mm, partially threaded
5.   Cannulated cancellous bone screw 4.0 mm, partially threaded
6.   Washer

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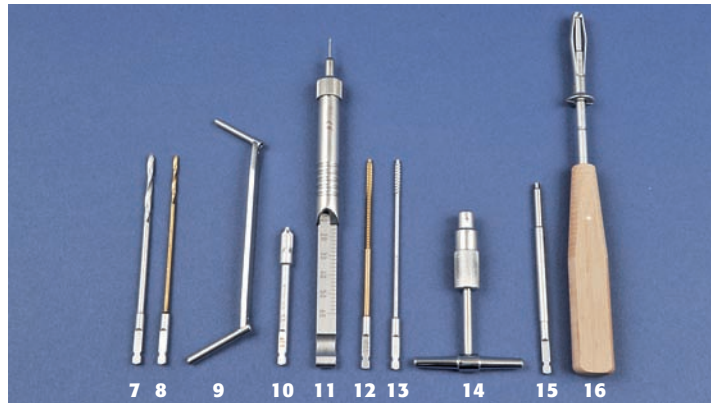
Fig 3.18-6b   Instruments for fracture fixation with one-third tubular plate 3.5
7.   Drill bit 3.5 mm
8.   Drill bit 2.5 mm
9.   Double drill sleeve 3.5/2.5 mm
10.   Countersink 3.5 mm
11.   Depth gauge
12.   Tap 3.5 mm for cortex screws
13.   Tap 4.0 mm for cancellous bone screws
14.   T-handle
15.   Screwdriver shaft
16.   Screwdriver with holding sleeve

Fig 3.18-6c   Instruments for fracture fixation with 4.0 mm cannulated screws
17.   Guide wire 1.25 mm, 150 mm long
18.   Direct measuring device
19.   Cannulated drill bit 2.7/1.35 mm
20.   Cannulated countersink 3.5/4.0 mm
21.   Double drill sleeve 2.7/1.25 mm
22.   Cannulated tap 4.0 mm
23.   Handle with quick coupling
24.   Cannulated screwdriver shaft
25.   Cannulated screwdriver with holding sleeve
26.   Screwdriver (normal)
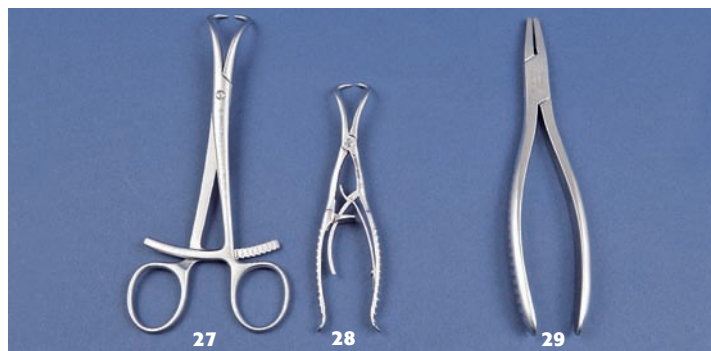
Fig 3.18-6d   Instruments for reduction and plate contouring
27.   Reduction forceps with points, large, ratchet lock
28.   Reduction forceps with points, small, soft lock
29.   Bending pliers

8 Procedure and technique—step-by-step

- Start the operation laterally with the fibula. Generally (due to the posterior syndesmotic ligaments), reduction of the fibula also reduces the posterior malleolus (Volkmann triangle). If reduction is difficult, the medial side should be exposed to clear the ankle joint of interposed ligament, osteochondral fragments, or hematoma.
- Fixation of the posterior malleolus fracture is only required if the fragment is larger than one quarter of the articular surface in the lateral view of the tibia.

Lateral malleolus
- Make a 10–15 cm straight lateral incision over the distal fibula. Preserve the sural nerve and superficial fibular nerve.
- Use gentle soft-tissue retraction to expose and carefully clear the fracture and joint of hematoma and debris.
- Reduce the fibula fracture anatomically with pointed reduction forceps by tilting them slightly (Fig 3.18-7a). This will be assisted by traction and internal rotation of the foot.
- Next, insert a 3.5 mm cortex screw as a lag screw across the fibula fracture.
- Drill a pilot hole through the near cortex with a 3.5 mm drill bit (Fig 3.18-7b).

- Use the 2.5 mm end of the double drill sleeve as a centralizer by pushing it into the hole, then drill a 2.5 mm drill hole through the far cortex (Fig 3.18-7c).
- Countersink the hole (Fig 3.18-7d), measure the depth (Fig 3.18-7e), and tap the bone with the (gold-colored) 3.5 mm cortical tap (Fig 3.18-7f).
- Insert the appropriate length cortex screw and observe the interfragmentary compression as it is tightened (Fig 3.18-7g).
- Choose a 5–6 hole one-third tubular plate 3.5 and contour it with bending pliers to match the distal end of the fibula.
- Fix the plate with at least two 3.5 mm cortex screws on either side of the lag screw. Drill the hole with a 2.5 mm drill bit, measure the depth, and tap the bone with the cortical tap. Insert the appropriate 3.5 mm cortical screw.
- Insert additional 3.5 mm cortex screws proximally.
- Distally, 4.0 mm cancellous bone screws may be required.
- Use the 2.5 mm drill and the 4.0 mm (silver) tap (Fig 3.18-7h).
- Ensure these distal screws do not penetrate the joint and check the position with the image intensifier.
- The plate acts as a protection plate.

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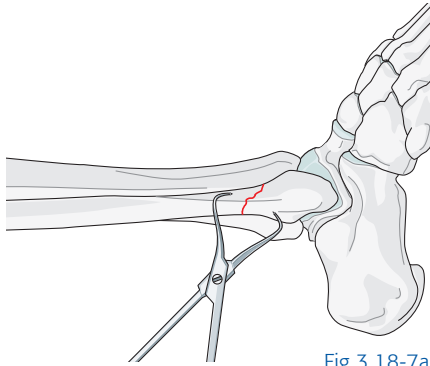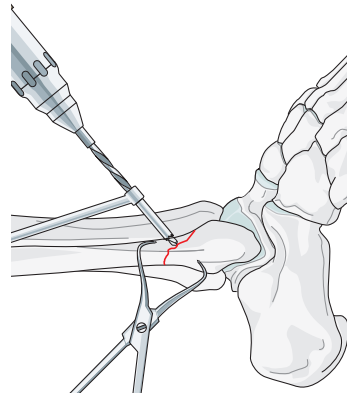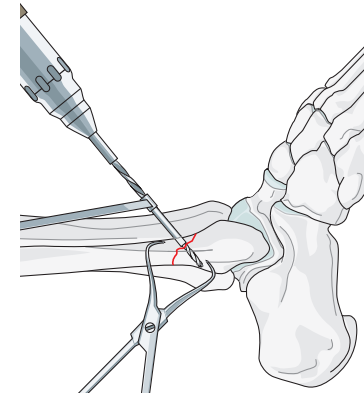
Fig 3.18-7a

Fig 3.18-7b

Fig 3.18-7c
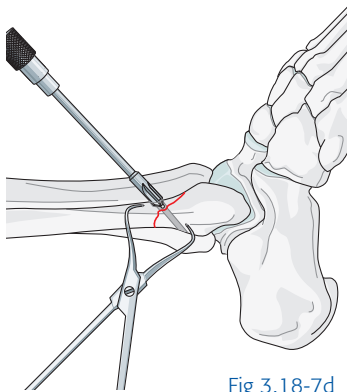
Fig 3.18-7d
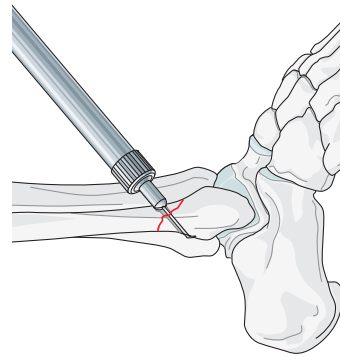
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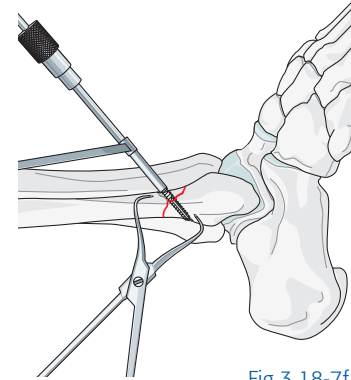
Fig 3.18-7f
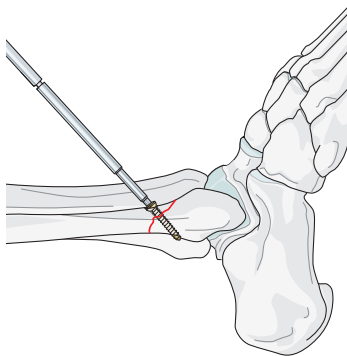
Fig 3.18-7g
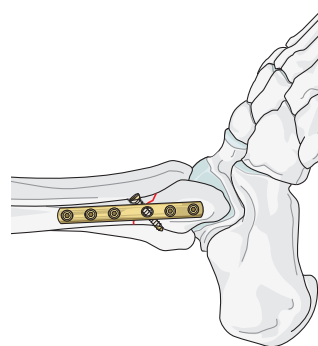
Fig 3.18-7h

Medial malleolus

- Make a curved medial incision running slightly anterior to the medial malleolus. Take care not to damage the saphenous vein and nerve. This anterior approach allows better inspection of the joint.
- Expose the fracture and remove any interposed soft tissue preventing reduction. Wash out the fracture hematoma and debris.
- Reduce the fracture anatomically using a pointed reduction forceps (Fig 3.18-8a) and fix it temporarily with one or two K-wires (Fig 3.18-8b).
- Check the reduction with the image intensifier.
- Remove one of the K-wires. Using the 2.5 mm drill bit and drill sleeve predrill for a partially threaded 4.0 mm cancellous bone screw (Fig 3.18-8c).

- Measure the length and tap with the 4.0 mm (silver) tap.
- Insert the appropriate 4.0 mm partially threaded cancellous bone screw to compress the fracture. A washer may be used in osteoporotic bone (Fig 3.18-8d).
- All screw threads must cross beyond the fracture site to achieve compression. Choose the shortest screw possible because the best-quality bone is found close to the joint line. In practice, a screw of about 30–35 mm is the right length in most adults.
- If possible, repeat the same steps for a second lag screw parallel to the first one (Fig 3.18-8e). If the size of the medial malleolus allows only one screw, then a K-wire may be left in place (with its end bent over) to secure rotational stability.
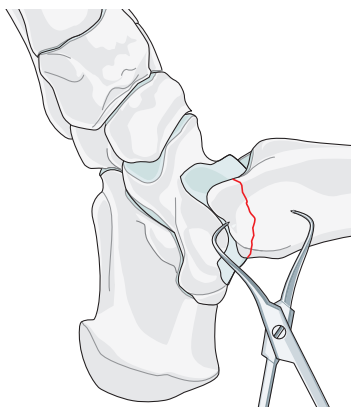
Fig 3.18-8a

Fig 3.18-8b

Fig 3.18-8c

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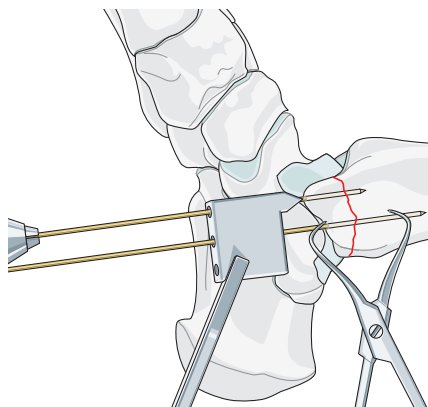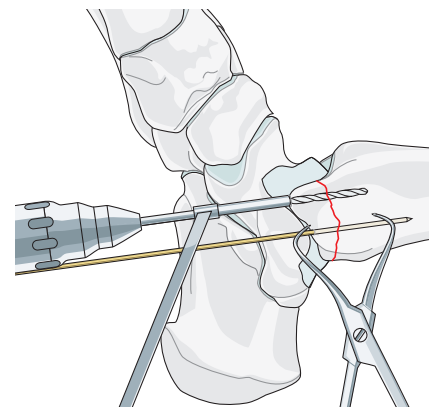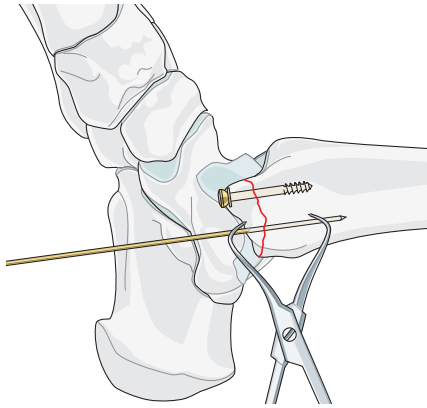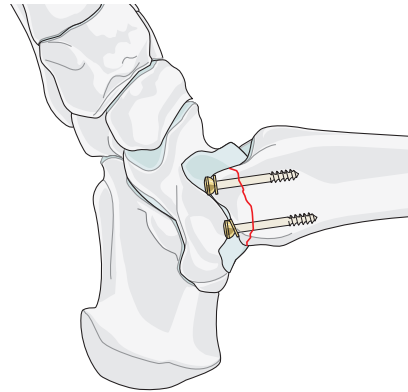
Fig 3.18-8d

Fig 3.18-8e

Posterior malleolus (Volkmann triangle)

- There are several techniques to reduce and fix this fragment. Here the technique of fixation front to back using cannulated 4.0 mm screws is described.
- Fixation of the posterior malleolus is only done when there is a large fragment (> 25% of the articular surface to be decided) and after the medial and lateral malleoli have been reduced and fixed anatomically.
- Reduction is achieved by ligamentotaxis, applying dorsiflexion to the foot, and holding the reduction with a dental hook through the lateral incision.
- Make a 1 cm incision anteriorly, close to the level of the joint and dissect bluntly down to the bone.
- Using the double drill guide 2.7/1.25, insert a 1.25 mm guide wire with threaded tip from front to back parallel to the joint to plan the cannulated screw position (Fig 3.18-9a).
- Check the reduction in a lateral view with the image intensifier.
- Slide the direct measuring device over the K-wire and determine screw length (Fig 3.18-9b).
- Sometimes countersinking or predrilling of the near cortex with the corresponding cannulated instruments over the guide wire is required (Fig 3.18-9c).

- Insert the appropriate length 4.0 mm self-drilling and self-tapping screw and a washer over the guide wire with the cannulated screwdriver (Fig 3.18-9d).
- Check reduction and fixation with the image intensifier (Fig 3.18-9e).
- Repeat the process if necessary and insert a second screw.
- A partially threaded screw can only apply compression at a fracture site if all the threads are anchored in the far fragment. If the posterior malleolar fragment is small then the screw threads of the cannulated 4.0 mm partially threaded cancellous bone screw will cross the fracture line and no compression will be obtained. In such cases use a fully threaded cortex screw with the classic lag screw technique for cortex screws.
- Check fixation with the image intensifier and make hard copies (AP and lateral) before skin closure.
- Irrigate and close the wounds.

Further information is available on AO Teaching video 24014: Ankle Fusion With Screws Through the Anterior Approach.
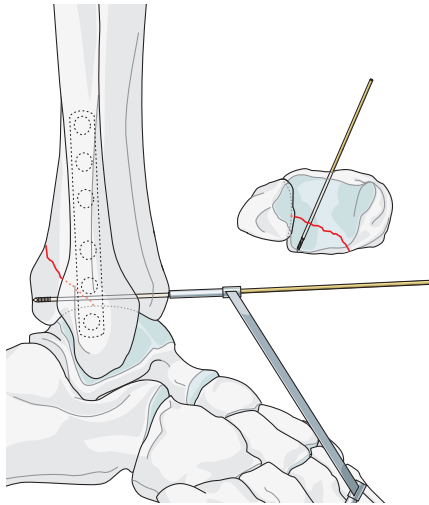
Fig 3.18-9a
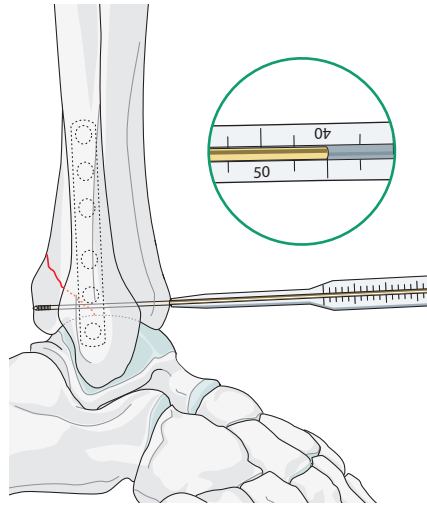
Fig 3.18-9b
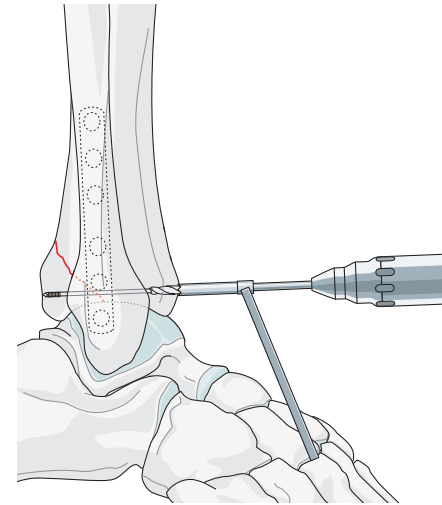
Fig 3.18-9c

Fig 3.18-9d

Fig 3.18-9e

Author   Rodrigo Pesantez
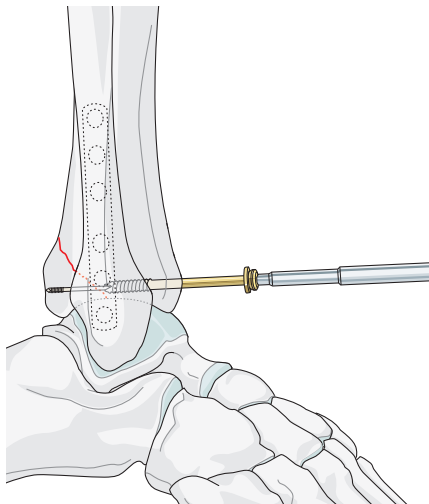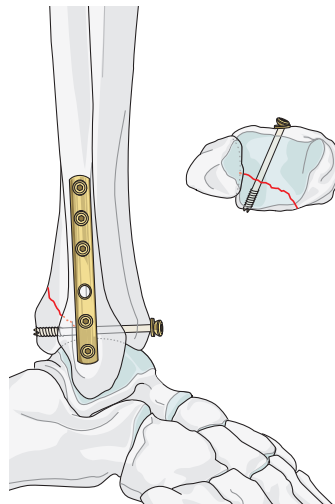
9   Specific perioperative care

- Take care to keep the operating field sterile when handling the C-arm.
- Do not penetrate the articular surface with any screws and check with the image intensifier.

10   Specific postoperative care

- Apply a U-shaped plaster of Paris splint to the lower leg with the foot in neutral position, allowing for active dorsiflexion.
- Start physiotherapy on postoperative day 1. As soon as active dorsiflexion of the foot is possible, remove the plaster splint.
- Compliant patients are allowed immediate partial weight bearing (10–15 kg). Full weight bearing is permitted after 6–8 weeks, depending on bone quality. A brace or cast gives good protection in noncompliant and osteoporotic patients.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments are available.
- Be prepared for application of different types of screws.
- Check screw design and length.
- Check matching K-wires 1.25 for cannulated screws.
- Always offer a conventional screwdriver when performing final tightening of the cannulated screws.
- Do not use a cannulated screwdriver for screw removal (it is too delicate), use a conventional screwdriver.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Evaluate soft tissues the day before surgery; these are the key to a successful outcome. If in any doubt, delay surgery.
- Make a preoperative plan including surgical approaches, reduction techniques, and implants to fix the fracture.
- Check that no screws have penetrated into the ankle joint.
- Restore mortise congruity—correct length of fibula, talocrural angle, and symmetrical joint space.
- Check the fixation with x-rays before skin closure.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

3.19   Calcaneal fractures

3.19   Calcaneal fractures

Case

- Calcaneal fracture (83-C2): stabilization with calcaneal locking plate

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Introduction

- The Müller AO/OTA Classification labels the calcaneus as bone 83 and further classifies fractures as follows:
  - type 82-A1: avulsion of the Achilles tendon with a piece of calcaneal tuberosity
  - type 82-B2: displaced fracture which is anterior to the joint
  - type 82-C2: displaced and intraarticular and involves the subtalar joint. This fracture, which is a severely displaced and impacted intraarticular calcaneal fracture, is described here.
- Calcaneal fractures are almost always caused by a fall from high, landing feet first. They tend to occur in the young, active population, those working at high level, or in sports (eg, hang gliding) or in elderly people climbing rooftops or trees.
- In a fall, the calcaneus is caught between the ground and the weight of the body, creating a displaced fracture. It may be accompanied by other bony injuries such as spine, pelvis, or extremity injuries.
- The fracture often results in significant soft-tissue swelling and fracture blisters.
- Ten percent of calcaneal fractures are open, usually on the medial side of the foot.
- A nondisplaced fracture is best treated without a cast and without weight bearing until it has healed. Early motion is usually recommended.
- Displaced fractures are often an indication for surgery and patients should always undergo a computed tomographic (CT) scan.

Müller AO/OTA Classification—calcaneus

82-A1	82-A2	82-A3
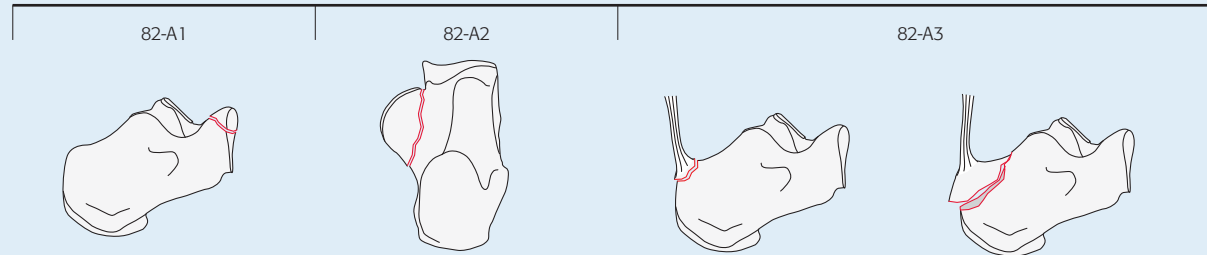
82-A   avulsion or process or tuberosity
82-A1   anterior process
82-A2   medial, sustenaculum
82-A3   tuberosity

82-B1	82-B2
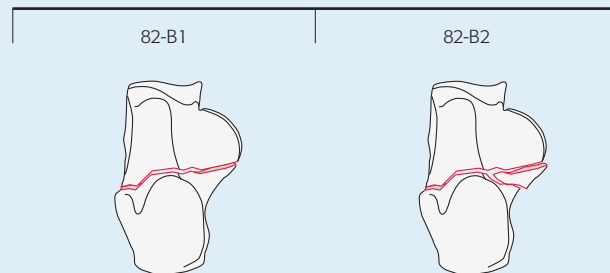
82-B   nonarticular body fractures
82-B1   noncomminuted
82-B2   comminuted

82-C1	82-C2	82-C3	82-C4
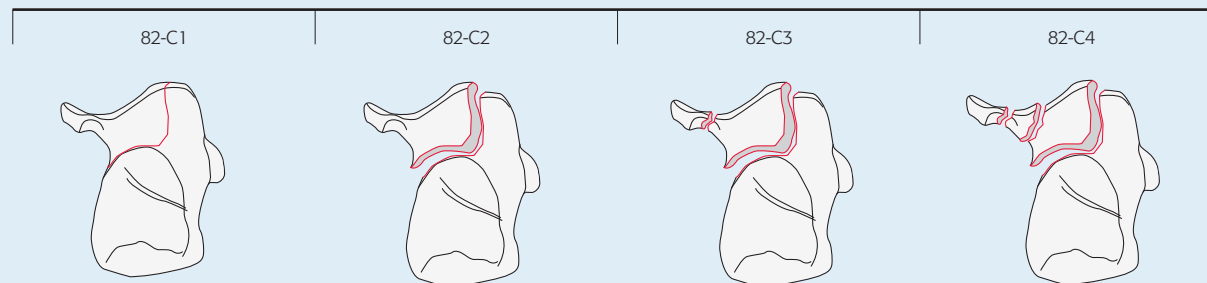
82-C   articular fracture involving posterior facet
82-C1   nondisplaced
82-C2   two part fractures
82-C3   three part fractures
82-C4   four or more parts

Author   Richard Buckley

3.19.1   Calcaneal fracture (83-C2): stabilization with calcaneal locking plate

Surgical management

- Stabilization with calcaneal locking plate

Alternative implants

- Calcaneal plate 3.5 with conventional 3.5 mm cortex screws and 4.0 mm cancellous bone screws
- One-third tubular plate 3.5
- H-plate 3.5

1   Introduction
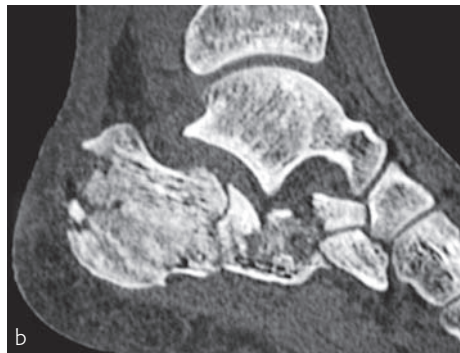
Fig 3.19-1a–c
a   Preoperative x-ray: displaced complex intraarticular calcaneal fracture.
b   Preoperative CT scan: severe communition and displacement.
c   Postoperative x-ray: stabilization with lag screw and calcaneal locking plate.

- There is usually a significant related soft-tissue injury. This must be allowed to resolve before surgery can be safely performed because the extensive surgical approach (lateral flap) is at risk of wound breakdown if surgery is attempted too early. This may necessitate waiting up to 3 weeks (Fig 3.19-2).
- Relative contraindications for surgery include smoking, poor-quality bone, and diabetes.
- Extraarticular, displaced calcaneal fractures may be treated with percutaneous techniques; however, intraarticular fractures which are displaced and impacted require a formal open approach and internal fixation with locking or nonlocking plates and screws.

Fig 3.19-2   Soft-tissue injury and blisters in a patient with a calcaneal fracture. The recovery of the skin is crucial before surgery can be performed.

2   Preoperative preparation

Operating room personnel (ORP) need to know and confirm:
- Site and side of fracture
- Type of operation planned
- Ensure that operative site has been marked by the surgeon
- Condition of the soft tissues
- Implant to be used (note: plates are in right and left versions)
- Patient positioning
- Details of the patient (including a signed consent form and appropriate antibiotic and thromboprophylaxis)
- Comorbidities, including allergies

Instrumentation required:
- Small fragment instruments
- Calcaneal locking plates, right or left depending on side of injury
- Corresponding screws (3.5 mm locking head screws; 3.5 mm and 2.7 mm cortex screws, 4.0 mm cancellous bone screws)
- Corresponding bending templates and pliers
- Set of K-wires
- 4.0 or 5.0 mm Schanz screws, T-handle, and corresponding drill bit
- Femoral distractor set for reduction
- Bone graft-harvesting set
- Bone substitute biomaterial (to fill large bony defect, if required)
- General orthopaedic instruments
- Compatible air or battery drill with attachments

Equipment:
- Operating table with positioning accessories to assist with lateral positioning of the patient
- Image intensifier
- X-ray protection devices for personnel and patient
- Tourniquet (optional)

Author   Richard Buckley

3   Anesthesia

- This procedure is performed with the patient under general or regional anesthesia.

4   Patient and x-ray positioning

- Place the patient in the lateral position with the affected side placed upward. The dependent side of the patient is well padded over all bony prominences (Fig 3.19-3).
- Protect any critical soft-tissue areas.
- The surgeon must check the final positioning before the patient undergoes skin disinfection.
- Apply a tourniquet to the thigh of the affected side. Only inflate it if required.
- Ensure that the image intensifier can obtain true lateral images of the hindfoot and axial images of the calcaneus.
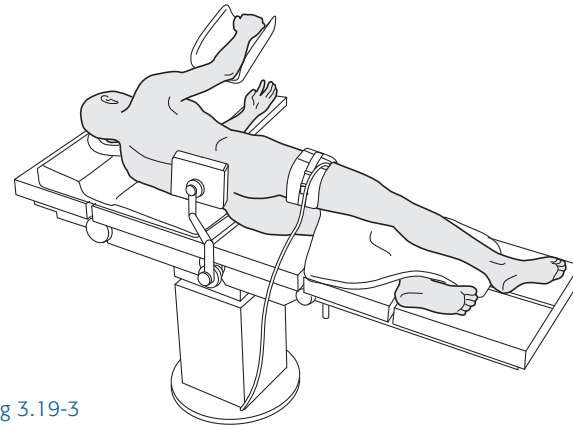
Fig 3.19-3

5   Skin disinfecting and draping

- Disinfect the exposed area of the limb with the appropriate antiseptic (Fig 3.19-4a).
- Disinfect the pelvic crest (in case this is required for bone harvesting).
- Start by draping the pelvic crest and then continue with the limb.
- Use a single-use waterproof drape, followed by a limb drape (Fig 3.19-4b).
- Drape the image intensifier.
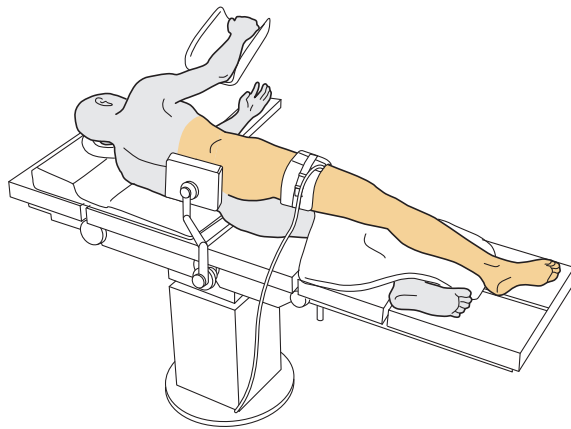
Fig 3.19-4a

Fig 3.19-4b

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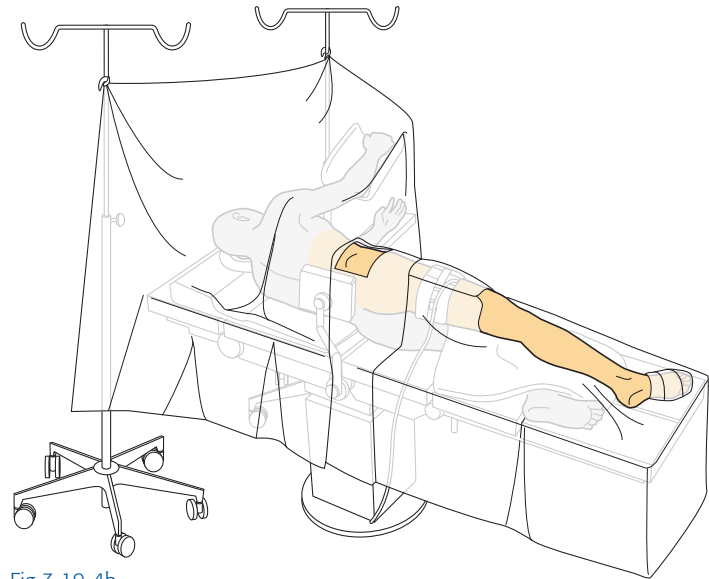
6   Operating room set-up

- The surgeon stands (or sits) facing the patient's calcaneus, and the assistant is opposite.
- The ORP stands next to the surgeons.
- Put a sterile bump beneath the surface of the affected ankle. This allows the foot to fall slightly into varus.
- Bring the image intensifier in from the foot of the OR table for lateral and axial images.
- Place the image intensifier display screen in full view of the surgical team and the radiographer (Fig 3.19-5).
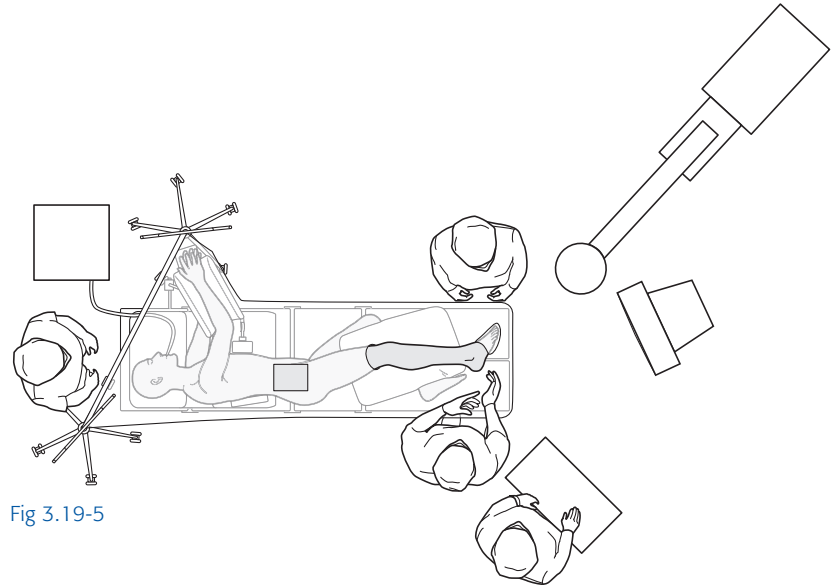
Fig 3.19-5

7   Instrumentation
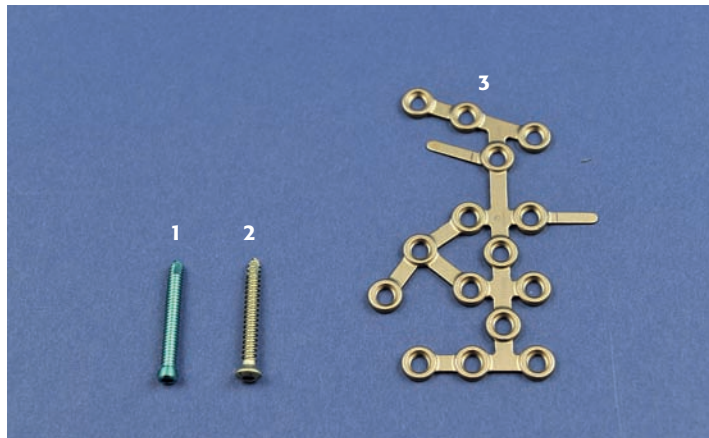
Fig 3.19-6a   Implants
1.   Locking head screw 3.5 mm
2.   Cortex screw 3.5 mm, self-tapping
3.   Calcaneal locking plate, right
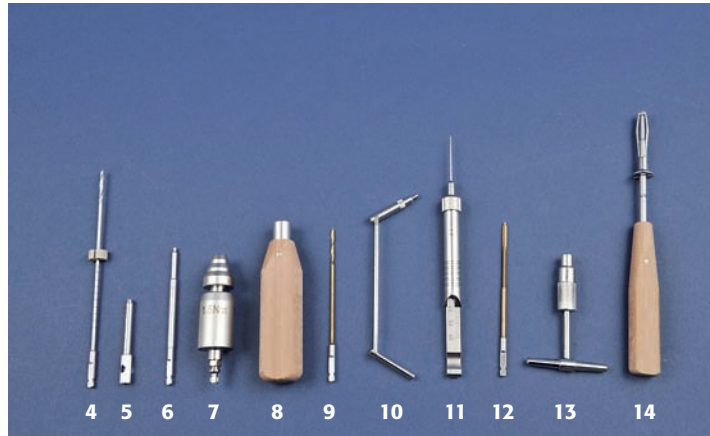
Fig 3.19-6b   Instruments for fracture fixation with calcaneal plate 3.5
4.   LCP drill bit 2.8 mm
5.   LCP drill sleeve 3.5 mm
6.   Screwdriver shaft
7.   Torque limiter 1.5 Nm with quick coupling
8.   Handle with quick coupling
9.   Drill bit 2.5 mm
10.   Universal drill sleeve 3.5 mm
11.   Depth gauge
12.   Tap 3.5 for cortex screws
13.   T-handle
14.   Screwdriver with holding sleeve
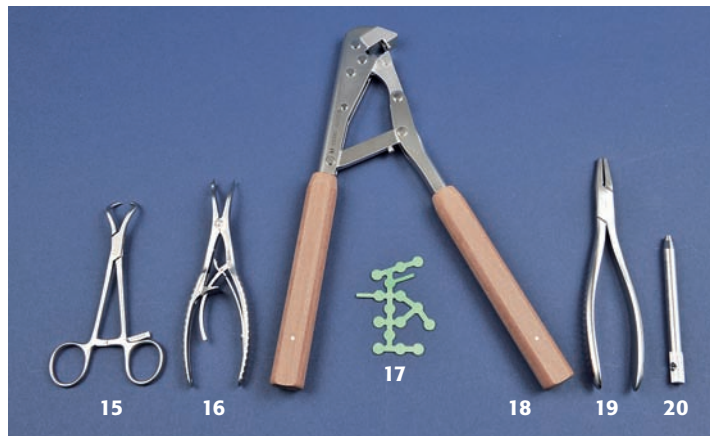
Fig 3.19-6c   Instruments for reduction, contouring, and cutting
15.   Reduction forceps with points, medium
16.   Bone spreader, soft lock, medium
17.   Bending template for calcaneal plate
18.   Cutting pliers
19.   Bending pliers
20.   Bending pin

Author Richard Buckley

8 Procedure and technique—step-by-step

- Make an L-shaped incision on the lateral side of the calcaneus and create a full-thickness flap. The peroneal tendons and the sural nerve are usually included in the flap.
- Drill K-wires (1.6–1.8 mm) into the talus to gently retract the flap.
- Flip the lateral wall of the calcaneus posteriorly or distally, revealing the impacted subtalar joint.
- A 5.0 mm Schanz screw or a 2.0 mm K-wire may be applied to the posterolateral calcaneus to assist reduction by traction (Fig 3.19-7a).
- In delayed cases the use of a distractor (mid size) may be helpful to explore the subtalar joint and to maintain the correct height of the calcaneus. It should be applied between the tuber calcanei and the tibia.
- Clean the subtalar joint of clot with large amounts of irrigation.
- Use small elevators and bone hooks as well as the lamina spreader to restore the anatomy of the articular surface of the posterior joint facet of the calcaneum.
- If the fragments are completely loose and devitalized, they may be taken to the instrument table for easier reconstruction. Once anatomically reconstructed and fixed by K-wires, they are placed back into the subtalar space and fixed with preliminary K-wires (1.6 mm).
- Use K-wires to hold reduction.
- With the posterior joint facet reconstructed, the height of the calcaneus restored, any central bony defect can be filled with autogenous bone graft or with a bone substitute to support the reduced fragments.
- Make sure the harvested bone graft is kept moist and in a safe place until it is used (two separate cups are advisable).

- Use small impactors to insert the graft chips.
- Check the result of the reconstruction with the image intensifier.
- Reduce the lateral wall to the reconstructed calcaneus, and now apply a lateral calcaneal locking plate.
- Choose a right calcaneal locking plate.
- Contour and cut plate exactly. Use corresponding bending template, bending pliers, and cutters. Some branches of the plate may have to be shortened or removed to meet the individual shape of the bone.
- Position the plate carefully using two bending pins.
- Insert screws. Different screw types can be used with this plate depending on desired function.
- Insert drill sleeve and use drill bit 2.8 mm for 3.5 mm locking head screws.
- Use a universal drill guide and 2.5 mm drill bit for 3.5 mm conventional cortex screws or 4.0 mm cancellous bone screws.
- Sometimes even smaller 2.7 mm cortex screws are used with a sleeve and drill bit 2.0 mm.
- Try to use lag screws to reconstruct the subtalar joint.
- Usually not all plate holes are filled (Fig 3.19-7b).
- Take and save copies of final x-rays. Ensure that no screws or K-wires protrude into the joint.
- Close the wounds.

Further information is available on AO Teaching video 24026: ORIF of Intra-articular Calcaneal Fractures With the Locking Calcaneal Plate.
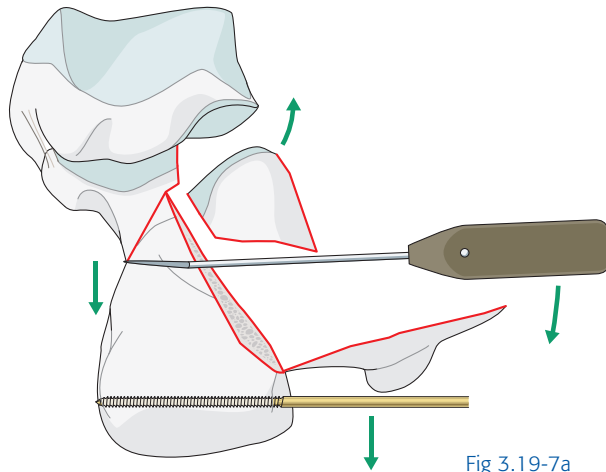
Fig 3.19-7a
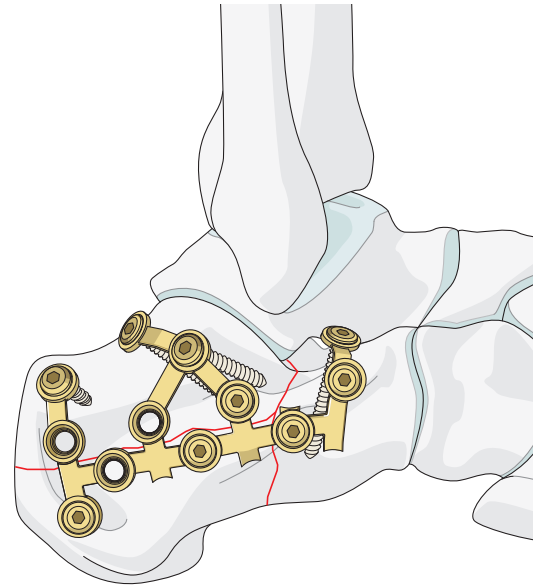
Fig 3.19-7b

9   Specific perioperative care

- Be careful with pressure areas.
- Make sure that the patient is secured on the OR table in the lateral position.
- Watch soft tissues of the foot carefully and ensure that all tenuous areas are carefully protected.
- Maintain sterility as the image intensifier is moved around the surgical field.

Author   Richard Buckley

10   Specific postoperative care

- X-rays must be taken postoperatively (possibly a CT scan as well).
- The fixation should allow safe positioning and handling of the patient for nursing.
- Apply a postoperative splint to prevent a drop foot.
- Assisted and active movement of the ankle and forefoot should be started immediately.
- Patients must remain nonweight bearing for 6–12 weeks postoperatively.

11   ORP—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Check that the full range of implants and instruments is available.
- Verify that calcaneal locking plates for operative site are available.
- Be aware of right and left plates.
- Have nonlocking calcaneal plates at hand (just in case).
- Make sure there are enough 1.6–2.0 mm K-wires.
- Confirm that Schanz screws are available.
- Do not confuse drill bits for the different types of screws.
- At the end of the procedure check that all used wires and cut plate pieces are removed from the patient.
- Discard used K-wires after use.
- Document and reorder all implants used.

12   Surgeon—key points

- Cross-check that details of the patient, side, marking, and site of surgery are correct.
- Good patient set-up and preoperative planning is essential.
- Recovery of soft tissues should occur before surgery (approximately 10–20 days).
- A clear understanding of the fracture pattern from plain films and CT is required, as well as a detailed plan for the procedure.
- Careful reconstruction of the articular surface of the posterior joint facet and its anatomical reduction into the subtalar space is essential. Equally important is the restoration of the correct height and length of the calcaneus.
- Make sure the axial alignment (varus/valgus) is correct.
- It is recommended to reconstruct the hindfoot from medial to lateral and from anterior to posterior.
- A Schanz screw or distractor inserted into the large posterior tuber of the calcaneus is often used for reduction.
- Multiple K-wires assist in the reduction and maintain it temporarily before the definitive fixation.
- The articular block is reconstructed with lag screws that are usually inserted outside the plate. The plate is used to stabilize the other fracture elements.
- Intraoperative x-rays are mandatory to ensure anatomical reduction and that there is no hardware protruding into the joint. A postoperative CT scan is recommended as well.
- Gentle soft-tissue care is obligatory.
- Early and intensive postoperative physiotherapy is crucial.
- Write a clear and legible record of the procedure, including specific postoperative instructions.

Glossary

Prepared by Chris L Colton with acknowledgments to Chris G Moran and Stephan M Perren

abduction: Movement of a part away from the midline, eg, abduction at the shoulder moves the arm away from the trunk and out to the side. At the thumb, it describes movement of the digit forward from the anatomical position, away from the palm. This is because, in evolutionary terms, the thumb of the primitive hand lies in the same plane as the fingers and abduction carries it sideways away from the midline, just like the arm abducts at the shoulder. In man, the thumb has rotated from its atavistic position, through 90°, to allow human grasp.

adduction: Movement of a part towards the midline, eg, adduction at the hip joint moves the leg toward the midline and adduction of both legs would press the knees together or cross the legs.

algodystrophy: See **reflex sympathetic dystrophy, complex regional pain syndrome.**

allodynia: Pain from stimuli that are not normally painful, or pain that occurs other than in the area stimulated.

allograft: Graft of tissue from another individual of the same species, who is genetically different from the recipient.

Bone is generally transplanted without revascularisation. Histocompatibility studies (tissue typing), essential in organ transplantation, are not necessary in bone allografting.

anaerobic: Those metabolic processes which are not dependent on oxygen. Anaerobic organisms can therefore thrive in tissues which are hypoxic or anoxic.

anastomosis: A junction between two vessels, or other tubular anatomical structures.

anatomical position: The reference position of the body—standing facing the observer, with the palms of the hands facing forward.

anatomical reduction: The exact adaptation of fracture fragments (hairline adjustment) in preparation for surgical fixation. It will result in complete restoration of the normal anatomy. While overall stability does not necessarily depend on precise reduction, precise reduction more reliably results in stability and increased strength of fixation. It is more important in articular fractures than in diaphyseal fractures—see also **stability of fixation**.

angular stability: The property of an implant for fracture stabilisation, which is designed in such a way that the discreet parts of the implant, when assembled, are fixed in

their angular relationship to each other. Usually applied to plates and screws, when the screw heads, once driven home in the plate hole, bind to the plate—this is achieved by an external thread on the screw head which engages with an internal thread in the plate hole. This principle was first described in 1935 by Rheinhold (France). See **locking plate**.

angulation: The orientation of one body (eg, bone fragment) to another in such a manner that the two parts meet at an angle other than a straight line. The standard surgical convention is that the angulation is characterized by describing the deviation of the distal part from its anatomical position. For example, at a Colles' fracture, the distal radial fragment is dorsally (or posteriorly) angulated, even though the apex of the deformity points anteriorly: similarly a tibial fracture whose apex of angulation points backwards should be referred to as angulated anteriorly, as the distal part is indeed angulated anteriorly from its anatomical position. See **deformity**.

ankylosis: Fusion of a joint by bone or a tight fibrous union, occurring as a result of a disease process, eg, following septic arthritis (pyarthrosis), in ankylosing spondylitis, healed tuberculosis of bone, etc.

antalgic: Literally against pain. Used to describe an alteration of gait, where the

stance phase one side is abruptly shortened to avoid weight-bearing pain in that leg.

anterior: The front aspect of the body in the anatomical position. If A is in front of B in the anatomical position, then A is said to be anterior to B.

antibiotic: Any drug, such as penicillin, produced by certain fungi, bacteria, and other organisms, which can inhibit the growth of (bacteriostatic), or destroy (**bactericidal**), micro-organisms. They are used for the prevention or treatment of infections.

antibody: A substance produced by the host's immune system in response to the detection of an **antigen**. The antibody is specifically elaborated to attack and destroy only the antigen which stimulated its production—antigen specific.

antigen: Component of a foreign biological substance (transplanted tissue, invading virus, etc), which stimulates the host's immune system to attack that foreign substance by elaborating an **antibody** that destroys the antigen and, in so doing, usually results in damage to the "invader."

arthritis: Literally, an inflammatory condition of a diarthrodial (**synovial**) joint. It may be septic or aseptic. The former may be blood-borne infection (haematogenous), more common in children, or it may follow penetration of the joint by wounding or

surgery. Aseptic arthritides are usually of the rheumatoid type (including Reiter's syndrome, psoriatic arthropathy, etc), or due to degenerative change (see **osteoarthritis, rheumatoid arthritis**).

arthrodesis: Fusion of a joint by bone, as a planned outcome of a surgical procedure.

articular fracture—partial: These fractures involve only part of the articular surface, while the rest of that surface remains attached to the diaphysis. There are several varieties:
– pure split: a fracture, resulting from a shearing force, in which the direction of the split is usually longitudinal.
– pure depression: an articular fracture in which there is pure depression of the articular surface without a split. The depression may be central or peripheral.
– split-depression: a combination of a split and a depression, in which the joint fragments are usually separated.
– multifragmentary depression: a fracture in which part of the joint is depressed and the fragments are completely separated.

articular fracture—complete: The articular surface is disrupted and completely separated from the diaphysis. The severity of these fractures depends on whether their articular and metaphyseal components are simple or multifragmentary.

atrophic nonunion: If a fracture fails to heal because the biological responses leading

to bony union are frustrated, usually due to adverse biological status of the fracture locus, the nonunion is categorised as atrophic, with absence of callus, rounding off of the bone ends and finally the formation of a false joint, or **pseudarthrosis**. See **nonunion**.

autograft: Graft of tissue from one site to another within the same individual (homograft).

avascular necrosis: Bone which has been deprived of its blood supply dies. In the absence of sepsis, this is called avascular necrosis (aseptic necrosis). The dead bone retains its normal strength until the natural process of revascularisation by **creeping substitution** (see **blood supply**) starts to remove the dead bone, in preparation for the laying down of new bone. Loaded areas may then collapse—segmental collapse. This occurs in the femoral head and the talus more frequently than at other skeletal sites.

avulsion: Pulling off.

bactericidal: Capable of killing bacteria.

biocompatibility: The ability to exist in harmony with, and not to injure, associated biological tissues or processes.

biological (biologically respectful) internal fixation: In any internal fixation there is always a skilful balance to be struck between the degree of surgical stabilization produced and the biological insult caused by

the necessary surgical intervention. The benefits of each will be judged by an experienced surgeon. Biological fixation utilizes a surgical exposure technique which favours the preservation of the blood supply, and thereby optimizes the healing potential of the bone and soft tissues, while providing sufficient stability for multifragmentary fractures to heal in correct length and alignment. For the protection of the implants from mechanical failure (fatigue or loosening), it relies on a rapid biological healing reaction (early **callus** formation).

biopsy: The surgical removal of a piece of tissue for histological or microbiological examination, usually undertaken to establish a diagnosis.

blood supply to cortical bone (restoration of): Cortical bone which has been completely deprived of its blood supply for any extended period of time dies. It may become revascularised, either by in-growth of blood vessels without marked widening of the Haversian canals (Pfister et al, 1979), or by newly formed **Haversian** canals, which result from the penetration of **osteons**. Such osteonal remodelling is a process with a marked lag period and a slow speed (0.1 mm/day according to Schenk, 1987). When aseptic necrotic bone is revascularised by resorption and replacement with newly formed vascular bone the term **creeping substitution** is often applied. See **vascularity** and **avascular necrosis**.

bone graft: Bone removed from one skeletal site and placed at another. Bone grafts are used to stimulate bone union and also to restore skeletal continuity where there has been bone loss—see **allograft, autograft, xenograft**.

broad spectrum: Refers to antibiotics which are active against a wide spectrum of different organisms.

butterfly fragment: Where there is a fracture complex with a third fragment which does not comprise a full cross-section of the bone (ie, after reduction there is some contact between the two main fragments), the small wedge-shaped fragment, which may be spiral, is occasionally referred to as a butterfly fragment—see **wedge fracture**.

buttress: An implant applied in such a manner as to press against a fragment and prevent its axial displacement under compressive physiological load, maintaining its reduction "out to length," is said to be functioning as a buttress. An example would be a contoured plate applied to the upper end of the tibia to prop up the surgically elevated main articular fragment of a tibial plateau fracture, thereby preventing its redisplacement into a position of depression. A buttress is defined by the Oxford English Dictionary as a structure of wood, stone, or brick, built against a wall to strengthen, or support it. Derived from the Fr. bo(u)terez—a thrusting arch. The flying buttresses of cathedrals are architectural examples.

callus: Callus formation is the response of living bone to any irritation—chemical (Küntscher, 1970), infective, mechanical instability (Hutzschenreuter et al, 1969), etc. Callus is a tissue complex formed at a site of bony repair. Fracture healing tissue makes a gradual and progressive transition through a series of tissue types:
- haematoma
- granulation tissue
- fibrous tissue (or fibro-cartilaginous tissue)
- remodelling into woven bone, gaining in stiffness as it does so.

In internal fixation with anatomical reduction and absolute stability, where direct (callus-free) bone healing is expected, the appearance of callus is a sign of unexpected mechanical instability and should alert the surgeon to a failure of the original mechanical objective (formerly referred to as "irritation" callus). Callus is welcome as a repair tissue in all treatment methods where only relative fracture stability has been the planned goal.

cancellous bone: Is the spongy trabecular bone (spongiosa) found mostly at the proximal and distal diaphyseal bone ends in contrast with the dense cortical bone of the shafts. Cancellous bone has a much larger surface area per unit volume and is, therefore, more readily available to the blood supply, as well as to osteoclasts for resorption. Its large surface/volume ratio also offers more surfaces for invading blood vessels when attempting to revascularise dead cancellous bone and this is an advantage

when cancellous bone is used for bone grafting.

caudad: Literally "tailward." If A is nearer to the "tail", or coccyx, than B, then A is caudad of B.

caudal: Pertaining to the tail, or tail region, eg, caudal epidural injection.

causalgia: See **complex regional pain syndrome.**

cephalad: Literally "headward." If A is nearer to the head than B, then A is cephalad of B.

chemotherapy: Treatment of malignant lesions with drugs that impair, or stop, their cellular proliferation.

chondral: Pertaining to cartilage, consisting of cartilage.

condrocytes: The active cells of all cartilage, whether articular cartilage, growth cartilage, fibrocartilage, etc. They produce the chondral matrix, both its collagen and the mucopolysaccharides of the ground substance.

cis–cortex: See **near cortex.**

comminution, comminuted: Refers to a fracture with multiple fragments that is more than two main fragments. Syn. **multifragmentary.**

compartment syndrome: See **muscle compartment.**

complex fracture: Fracture in which, after reduction, there is no contact between the main fragments.

complex regional pain syndrome:
Complex regional pain syndrome (CRPS) is a disorder of unknown pathophysiology, which can affect either the upper or lower limbs. This disabling syndrome is not related to a single nerve territory and is disproportionate to the initiating event. The most prominent features include burning pain and functional impairment of the affected limb. Only 1 in 5 patients returns to a normal level of function. Categorised as types I and II; the clinical features of CRPS type I comprise regional pain, sensory change, allodynia, abnormalities of temperature regulation, abnormal sudomotor activity, oedema, and skin discolouration, accompanying noxious events. CRPS type II includes the aforementioned features, but in association with a peripheral nerve lesion. The incidence of CRPS is approximately 1 in 2000 traumatic events. Previously CRPS type I was known as **reflex sympathetic dystrophy** and CRPS type II was known as **causalgia**.
In order to establish a diagnosis of CRPS, three of the following four criteria must be present:
– an initiating, noxious event, or cause of immobilisation.
– continuing pain, **allodynia** (pain from stimuli that are not normally painful, or

pain that occurs other than in the area stimulated), or excess pain, disproportionate to the irritating event.
– oedema, altered skin blood flow, or abnormal sweating in the region of the pain at some time.
– the diagnosis is excluded by absence of a condition to account for the degree of pain and dysfunction.

compound fracture: The British school has long referred to fractures with an overlying, communicating wound of the integument as "compound" fractures, the opposite being "simple" fractures. No fracture should be regarded as simple, and the use of the archaic word "compound" does not convey the important clinical distinction. Now largely superseded by **open fracture.**

compression screw: See **lag screw**.

compression: The act of pressing together. It can result in deformation (as in shortening a spring) and improvement in, or creation of, stability. Compression is used (a) to provide absolute stability of fracture fixation, where indicated, and (b) to protect the fixation implants and to improve their efficiency by reducing the dynamic stresses on them. Unloading is achieved through restoration of the load bearing capacity of the bone. Any fixation taking advantage of the load bearing capacity of fracture fragments can withstand load without mechanical failure, or temporary micromotion, at the fracture. This is the main reason for using careful reduction

and the application of compression. If the implant (screw, plate) bridging the fracture is applied under tension, then the fracture locus undergoes an equivalent amount of compression. The compression is used to help stabilize the fracture. Compression does not confer any "magic biological effect" on fracture healing—it merely provides the degree of absolute stability deemed necessary by the decision-making surgeon.

contact healing: Occurs between two fragment ends of a fractured bone, at places which are maintained in motionless contact. The fracture is then repaired by direct osteonal remodelling. Contact healing may also be observed where the gap is only a few micrometers wide. See **direct healing.**

continuous passive motion: see **CPM**.

coronal: This is a vertical plane of the body passing from side to side, so that a coronal bisection of the body would cut it into a front half and a back half. It is so-called because at a coronation, the crown (corona in Latin) is held with a hand on either side as it is lowered onto the royal head; the line joining these hands is in the "coronal" plane.

cortex: See **cortical bone.**

cortical bone: The dense bone forming the tubular element of the shaft, or diaphysis (middle part) of a long bone. The term cortex is also applied to the dense, thin shell covering the cancellous bone of the metaphysis. The two terms are generally used interchangeably.

corticotomy: A special osteotomy where the cortex is surgically divided, but the medullary contents and the periosteum are not.

CPM—continuous passive motion: The use of powered apparatus to move a joint through a controlled range of motion has been shown to enhance articular cartilage healing after joint injury and to promote soft tissue recovery after surgery. Salter, Mitchell and Sheperd and others have demonstrated that the use of passive motion machines for continuous periods is necessary for cartilage repair. The indiscriminate use of CPM machines for prolonged periods for other indications can lead to muscle wasting and should be combined with other techniques of physical therapy.

creeping substitution: See **blood supply**, **avascular necrosis.**

cytoplasm: The non-nuclear substance of a cell.

debricolage: A French term signifying the process of mechanical failure of an internal fixation prior to the onset of solid bone healing.

débridement: Literally the "unbridling" of a wound. Strictly speaking, it refers to the extension of a wound and the opening up of the planes of the injured tissue, usually in the context of open fractures, as described by Amboise Paré in the 16th century. It has come to be used loosely to encompass the whole process of opening up of a wound, or pathological area (eg, bone infection), together with the surgical excision of all avascular, contaminated, infected, or other undesirable tissue.

deformity: Any abnormality of the form of a body part. The standard surgical convention is that the deformity is characterised by describing the deviation of the distal part from its anatomical position. Certain deformities have specific names—see **scoliosis**, **recurvatum**, etc.

degenerative joint disease (DJD): See **osteoarthritis.**

delayed union: The failure of a fracture to consolidate within the normally expected time, which varies according to age, fracture type and location. Delayed union, like union is a surgical judgment.

diaphysis: The cylindrical, or tubular, part between the ends of a long bone often referred to as the shaft.

direct healing: A type of fracture healing observed with absolutely stable (rigid) internal fixation. It is characterized by:
1. Absence of callus formation specific to the fracture site.
2. Absence of bone surface resorption at the fracture site.

3. Direct bone formation, without any intermediate repair tissue.

Direct fracture healing was formerly called "primary" healing, a term avoided today in order not to imply any suggestion of grading of the quality of fracture healing. Two types of direct healing are distinguished, namely **contact healing** and **gap healing.**

distal: Away from the centre of the body; more peripheral. For example, the hand is distal to the elbow; the phalanges are distal to the metacarpals. In certain instances, it means nearer the end than the beginning; for example, in the digestive system the stomach is distal to the oesophagus or, in the urinary tract, the bladder is distal to the ureter.

dorsal: Pertaining to the back, dorsum, of the body in the anatomical position. An exception is the foot; the top of the foot, even though it faces forward in the anatomical position, is called the dorsum.

ductility: The ability of a material to develop significant, permanent deformation before it breaks. See **plastic deformation**.

dynamisation: The mechanical load transferred across a fracture locus can be increased, at a certain healing stage, in order to enhance bone formation, or to promote "maturation" of the healing tissues. An example would be the reduction in stiffness of an external fixation, either by loosening some clamps, reducing the number of pins, or moving the tubular construct further from the bone. Early dynamisation, ie, before solid bridging of the bone, can result in stimulation of callus formation. The value of later dynamisation is debatable.

elastic deformation: See **plastic deformation.**

endosteal: The adjective derived from endosteum, which means the interior surface of a bone, ie, the wall of the medullary cavity.

energy transfer: When tissues are traumatised, the damage is due to energy that is transferred to those tissues. This is most commonly due to the transfer of **kinetic energy** from a moving object (car, missile, falling object, etc). The greater the amount of energy transferred to the tissue, the more extensive the damage.

epiphysis: The end of a long bone that bears the articular component (joint). The epiphysis develops embryologically from the cartilaginous element between the joint surface and the growth plate—see **metaphysis.**

extension: The movement of an articulation that causes the relationship between the part above the joint and the part below the joint to become straighter. An exception is "extension" of the foot at the ankle (so-called dorsiflexion); dorsiflexion is the better term, in this context.

extensor: Adjective from the noun "extension." The muscles which cause extension of a part are its extensor muscles; the surface of a part where those muscles are found is sometimes called the extensor surface.

extraarticular fracture: Does not involve the articular surface, but it may be intracapsular (as in fracture of the femoral neck).

far cortex (trans-cortex): The cortex more distant from the operator. In plating and tension band wiring, a bony defect has more important consequences in the far cortex than in the near cortex. This difference is due to the inability of a defective far cortex to resist compressive forces.

fascio–cutaneous: A term describing tissue flaps that include, as a single layer, the skin, the subcutaneous tissues, and the associated deep fascia.

fasciotomy: The surgical division of the investing fascial wall of an osseo-fascial muscle compartment, usually to release pathologically high intra-compartmental pressure—see **muscle compartment syndrome.**

fibrocartilage: Tissue consisting of elements of cartilage and of fibrous tissue. This may be a normal anatomical structure, such as certain intraarticular structures (menisci, triangular fibrocartilage at the wrist, or

temporo-mandibular joint, or the symphysis pubis), or may constitute the repair tissue after lesions of the articular (hyaline) cartilage.

fixation, flexible: Traditionally, internal fixation according to AO ASIF method meant absolutely stable (rigid) fixation, using close adaptation and compression of the bony fragments. Lately, a less stable fixation (flexible fixation using splinting plates, intramedullary nails, or fixators) has been observed to yield very good results under conditions in which the fragments are well vascularized. Given best preservation of the viability of the fragments, flexible fixation induces abundant and rapid callus formation. Recall that the combination of instability and compromise of the biology of the fracture locus is deleterious. See **biological internal fixation.**

flexion: The movement of an articulation that causes the relationship between the part above the joint and the part below the joint to become more angulated.

flexor: Adjective from the noun "flexion." The muscles which cause flexion of a part are flexor muscles; the surface of a part where those muscles are found is sometimes called the flexor surface.

floating knee: Isolation of the knee joint from the remainder of the skeleton by fractures of the femur and the tibia in the same limb.

fracture: A loss of continuity (breakage), usually sudden, of any structure resulting when internal stresses produced by load exceed the limits of its strength. The complexity and displacement of the fracture depend largely on the energy build-up in the structure prior to fracture. The shape of the fracture planes (transverse fracture, spiral fracture, avulsion, impaction, etc) is related to the nature of the load: compressive, bending, torsional, shear, or any combination of these.

fracture disease: A condition characterized by inappropriate pain, soft tissue swelling, patchy bone loss and joint stiffness (Lucas-Championnière, 1907). Fracture disease can best be avoided by that system of fracture management most likely to produce skeletal integrity, while permitting early active motion of the part (early functional rehabilitation) (Allgöwer, 1978).

fracture locus (injury zone): Locus derives from the Latin word for "place." It is used in this context to describe the biological unit comprising the fracture fragments and the immediately associated soft tissues, all of which function together to produce healing of the injury.

fracture, articular: Involves the articular surface. They are subdivided into partial and complete**.**

fracture, extraarticular: These do not involve the articular surface, although they

may be intracapsular. They include apophyseal and metaphyseal fractures.

fracture, impacted: A stable, and usually simple, fracture of the metaphysis or epiphysis in which the fragments are driven one into the other, resulting often in inherent fracture stability.

fracture, multifragmentary: A term used to characterize any fracture with one or more completely separated intermediate fragment(s). In the diaphyseal and metaphyseal segments, it includes the wedge and the complex fractures. The terms wedge and complex are used only for diaphyseal or metaphyseal fractures.
– wedge: A fracture with one or more intermediate fragment(s) in which, after reduction, there is some contact between the main fragments. The spiral, or bending, wedge may be intact, or fragmented.
– complex: A fracture with one or more intermediate fragment(s) in which, after reduction, there is no contact between the main proximal and distal fragments. The complex fractures are spiral, segmental or irregular. The term comminuted is imprecise and should not be used.

fracture, simple: A term used to characterize a single circumferential disruption of a diaphysis or metaphysis or a single disruption of an articular surface. Simple fractures of the diaphysis or metaphysis are spiral, oblique or transverse.

frontal: Pertaining to the front of the body in the anatomical position. That part of the skull forming the forehead is the frontal bone. The frontal plane of the body, parallel to the front, is the same as the **coronal plane.**

fusion: See **arthrodesis.**

Galeazzi injury: A fracture of the radial shaft associated with a dislocation of the inferior radioulnar joint. Its first description is attributed to Galeazzi (1934). Sometimes referred to as the "reversed **Monteggia.**"

gap healing: The healing process taking place between two fragment ends kept in stable relative position with a small gap between them. Gap healing progresses in two phases: (a) the filling of the gap with lamellar bone orientated parallel to the plane of the fracture gap, (b) the subsequent **osteonal** remodelling of the newly formed lamellar bone.

gliding hole: When a fully threaded screw is used as a **lag screw,** the cortex under the screw head (**near cortex**, or cis-cortex) should not engage the screw threads. This can be accomplished by over-drilling the near cortex hole to at least the size of the outer diameter of the screw thread.

gliding splint: A splint (such as an unlocked intramedullary nail) which allows for axial shortening. Such a splint provides the possibility for the reestablishment of bony coaptation under conditions of fragment end shortening due to bone surface resorption.

goal of fracture treatment: According to Müller et al (1963), the goal of fracture treatment is to restore optimal function of the limb in respect to mobility and load-bearing capacity. The goal is furthermore to prevent early complications, such as **reflex sympathetic dystrophy, fracture disease,** or Sudeck's atrophy and, in the case of polytrauma, multiple system organ failure, as well as late sequelae, such as post-traumatic arthrosis.

haematogenous: Blood-borne.

Haversian system: The cortical bone is composed of a system of small channels (osteons) about 0.1 mm in diameter. These channels contain the blood vessels and are remodelled after a disturbance of the blood supply to bone. There is a natural turnover of the Haversian systems by continuous osteonal remodelling; this process is part of the dynamic and metabolic nature of bone. It is also involved in the adaptation of bone to an altered mechanical environment.

Hawkin's test: A test for subacromial impingement at the shoulder. With the arm in the throwing position and flexed forward about 30 degrees, passively internally rotate the humerus. Pain suggests impingement of the supraspinatus tendon against the coracoacromial ligament. Crepitus can also often be detected at the subacromial bursa.

For shoulder examination, see **http://www. usask.ca/cme/articles/fmse/index.php**

healing: Restoration of original integrity. The healing process after a bone fracture lasts many years, until internal fracture remodelling subsides. For practical purposes, however, healing is considered to be complete when the bone has regained its normal stiffness and strength.

heterograft: See **allograft** and **xenograft**.

homograft: See **allograft** and **autograft**.

horizontal: Parallel with the horizon: unrelated to the anatomical position.

hypertrophic nonunion: If a fracture fails to heal, despite good fracture locus biology, due to a mechanical environment which is so unstable as to frustrate the tissue responses, the nonunion is categorised as hypertrophic. Abundant new bone formation will often produce the so-called "elephant's foot" appearance on x-ray. See **nonunion**.

hypovolaemia: A state where the circulating blood volume is reduced. This can occur due to haemorrhage, or other loss of fluid, such as dehydration. It can lead to shock.

hypoxia: A state where the oxygen level in the arterial blood, or in other tissue, is pathologically reduced.

impacted fracture: See **fracture, impacted.**

indirect healing: Bone healing as observed in fractures treated either with relative stability, or left untreated. Callus formation is predominant, the fracture fragment ends are resorbed, and bone formation results from a process of transformation of fibrous and/or cartilaginous tissue into bone—see **callus.**

inferior: Literally below or lesser than. In the anatomical position, if A is lower than B, A is inferior to B. The opposite is superior.

inoculation: The instillation, either accidental or deliberate, of microorganisms into body tissues, or into a culture medium.

interfragmentary compression: Static compression applied to a fracture plane imparts a high degree of stability to the fragments and thus reduces micromotion and strain. Bone surface resorption does not then occur. There is no demonstrable proof that interfragmentary compression, per se, has any effect upon internal remodelling of the cortical bone (Matter et al, 1974).

intramedullary nail—locked or unlocked: An intramedullary nail provides some degree of stability, mainly as a result of its (flexural) stiffness. An unlocked nail will allow the fragments to slide together along the nail; the fracture must therefore be provided with a solid support against shortening—see **gliding splint.** For the treatment of multifragmentary fractures, where there is axial instability (the fear of collapse into a shortened position), the nail can be interlocked above and below the fracture locus to prevent this shortening and also to reduce rotational displacement. This is achieved by locking bolts traversing a locking hole prepared in the nail and passing through the cortex on either side of the nail. If the locking hole is round and matches the size of the locking bolt, then static locking has been achieved. If the locking hole is elongated in the nail's long axis, the possibility of a limited excursion of axial movement is achieved, while preserving the rotational control— so-called dynamic locking.

ischaemia: Absence of blood flow.

kinetic energy: See **energy transfer.** The energy stored by the body by virtue of the fact that it is in motion. As energy cannot be destroyed, when a moving object is slowed or stopped, its kinetic energy is converted into other energy. If a moving object strikes a slower or stationary object, it imparts some of its kinetic energy to the body that it strikes. This may accelerate the other body (or parts of it), causing damage, or produce other energy transfer effects, such as heat production—the sparks seen when a metal bullet hits a rock, for example. Kinetic energy is calculated according to the formula $E = \frac{1}{2}mv^2$, where m is the mass of the moving object and v is its velocity.

kyphosis: Spinal deformity in which there is angulation forwards in the sagittal plane. Sharp angulation may result from abnormality of only one vertebral body, and is called an angular kyphosis, or gibbus (as after a severe wedge fracture, or tuberculous collapse of a vertebral body). A gentler kyphosis is due to deformity involving several adjacent vertebrae, as in osteoporosis affecting the thoracic spine ("Dowager's hump").

lag screw technique: Produces interfragmentary compression by driving the bone fragment beneath a screw head against another fragment in which the screw threads obtain purchase. The compression produced by a screw so inserted acts directly within the fracture surface and is therefore very efficient. A screw designed specifically for this purpose, being only partially threaded is a lag screw, or shaft screw. A full-threaded screw used with an over-sized hole in the near cortex to prevent thread purchase in the near fragment (a gliding hole) is strictly speaking not a lag screw but a threaded screw used with a lag technique; it is, nevertheless, often loosely termed a lag screw. Interfragmentary compression will be reduced by engagement of the screw threads with the walls of the gliding hole. Anchorage in the near fragment can be avoided by the use of a shaft screw. This technique is also required to maintain efficient compression when a screw is inserted through the plate and across a fracture plane in an inclined position.

lateral: Literally, of, or toward, the side. The side of the body in the anatomical position is the lateral aspect or surface. If A is nearer the side of the body than B (further from the midline), then A is lateral to B. The opposite is medial.

locking plate: A plate with threaded screw holes that allow mechanical coupling to a locking head screw. The Less Invasive Stabilisation System (LISS) will accept only this type of screw, whilst Locking Compression Plates (LCP) have a combination hole that will accept normal screw heads or threaded screw heads. See **angular stability.**

locking head screw: Screws with external threads cut onto the head, which provide a mechanical couple to an internal thread in the screw hole of a plate, thus creating a fixed angle device.

lymphoedema: Accumulation of oedema fluid in the tissues as a result of poor drainage of the lymph, usually due to the incompetence, or obstruction, of the lymphatic vessels.

malunion: Consolidation of a fracture in a position of **deformity.**

matrix: Literally, a place or medium in which something is bred, produced, or developed. In cartilage, it is the substance between the chondrocytes. It comprises a network of collagen fibres interspersed with a "jelly" of waterlogged mucopolysaccharide macromolecules (complex organic chemicals in large molecular chains).

medial: Literally, of or toward the middle, or median. The inner side of a part with the body in the anatomical position is the medial aspect or surface. If A is nearer the middle, or centre-line, than B, then A is medial to B. The opposite is lateral.

metaphysis: The segment of a long bone located between the articular end part (**epiphysis**) and the shaft (**diaphysis**). It consists mostly of **cancellous bone** within a thin cortical shell.

methylmethacrylate: A chemical substance, the monomer of which can be induced to polymerise, producing a hard plastic. It can be a form of bone cement (polymethylmethacrylate or PMMA), but in a different polymerised form it produces Perspex.

microvascular: Pertaining to microscopic blood vessels. Microvascular tissue transfer is related to the technical need for an operating microscope to perform the anastomoses (see **anastomosis**).

midline: The centre line of the body in the anatomical position.

minimally invasive plate osteosynthesis (MIPO): Reduction and plate fixation without direct surgical exposure of the fracture site, using small skin incisions and submuscular insertion of the plate.

Monteggia injury: A displaced ulnar fracture associated with a dislocation of the radial head from its articulation with the capitellum of the humerus, at the elbow. First described in the 19th century by the Italian physician Giovanni Battista Monteggia.

multifragmentary fracture: A term usually reserved for fractures which have one or more dissociated intermediate fragments.

muscle compartment: An anatomical space, bounded on all sides by bone and/or deep fascial envelope, which contains one or more muscle bellies. The relative inelasticity of its walls means that if the muscle tissue swells, the pressure in the osseo–fascial envelope can increase to levels which cut off the flow of blood to the muscle tissue, resulting in its severe compromise or death—so-called **muscle compartment syndrome.**

muscle compartment syndrome:
Diagnosis
In "Fractures with Soft Tissue Injuries," edited by Tscherne and Gotzen (1984), there is an excellent chapter on compartment syndrome. Under the heading of "Diagnosis of compartment syndromes, clinical examination" (p 83) it states:
"In the conscious patient, the earliest and most important symptom is of a burning, boring pain of acute onset which may be

spasmodic in nature and tends to increase with time. Sensory aberrations are also reported in the form of paraesthesiae, hypoaesthesiae, and rapid sensory losses. In co-operative patients, disturbances of muscular function are demonstrable as motor weakness after two to four hours of ischemia. On palpation, the affected muscles are tender and have a firm to stony-hard consistency. Peripheral arterial pulses and capillary perfusion are intact in the early stage, provided there is not concomitant arterial injury."

They then describe, as do most modern texts, techniques for direct measurement of compartment pressure in cases where there may be some doubt as to the diagnosis. In "Skeletal Trauma," edited by Browner, Jupiter, Levine and Trafton (1992), Rorabeck states: "Assuming the patient is conscious and alert, the most important symptom of an impending compartment syndrome is pain disproportionate to what might be expected given the problem the patient is being treated for. Frequently the patient presents with a relatively pain-free interval, perhaps a few hours following reduction of the fracture, and then develops pain out of proportion to the problem. The degree of pain can usually be assessed by the requirements for analgesia, or even stronger analgesia. The pain felt by the patient is unrelenting and seems to be unrelated to the position of the extremity or to immobilization. The patient might also complain of feelings of numbness or tingling in the affected extremity. These symptoms are poorly localized and are not to be relied

on. Clinical signs of an impending acute compartment syndrome, irrespective of the underlying cause, include pain on palpation of the swollen compartment, reproduction of symptoms with passive muscle stretch, sensory deficit in the territory of the nerve traversing the compartment and muscle weakness. The earliest sign of an acute compartment syndrome is a tensely swollen compartment, which on palpation reproduces the patient's pain." Treatment by **fasciotomy:** It is not always possible at fasciotomy to determine exactly which muscle has died and which has not, although this is usually evident when the muscles are reviewed 24 to 48 hours later. According to Tscherne and Gotzen (1984): "Decompressive fasciotomy is an emergency procedure, and facilities for this operation should be available at all times. Promptness has a critical bearing on the prognosis. According to McQuillen and Nolan (1968) and Matsen and Clawson (1975), disturbances of muscular microcirculation that persist longer than 12 hours produce significant motor and sensory deficits as well as myogenic contractures. Keays (1981) states that based on his experience good results are obtained only if decompression is performed within 6 hours of the onset of compartment syndrome. He further states that permanent defects may be expected after 8 hours, and that amputation will very likely be needed if surgery is delayed beyond 12 hours. Of his 10 patients treated by fibulectomy, only four had a good end result. Most findings on the temporal relationship between circulatory impairment and

reparative tissue tolerance are based on experimental total ischemia. Nerves showed functional deficits after only 30 minutes ischemia. Irreversible pareses developed after 12–24 hours of complete ischemia (Holmes et al, 1944; Malam 1963). Compensatable partial myogenic disturbances were observed after only 2–4 hours ischemia and an irreversible loss of function after 4–12 hours (Harman 1948; Whitesides 1971). These findings are consistent with our own clinical observation that permanent functional deficits arise within 4–6 hours of the onset of a frank, untreated compartment syndrome." This publication also quotes work of Oestern and Echtermeyer (1982), who reviewed 123 compartment syndromes, including late referrals. They reported: "Late sequelae developed in 36 patients, 35 of whom had a compartment syndrome of the lower leg. Twenty-nine displayed weak dorsiflexion of the foot, four had a claw-toe deformity and nine complained of sensory losses. Analysing the sequelae that occurred after fasciotomy, we find that late changes developed in only three patients who underwent a fasciotomy within the first 6 hours after their injury. By contrast, late changes occurred in 22 patients in whom decompression was delayed beyond 24 hours. Ten patients eventually had to undergo an amputation; in none of these cases had a decompressive fasciotomy been performed within the first 6 hours (1 within the first 12 hours, 2 between 12 and 24 hours and 7 more than 24 hours post-injury)." The results of Oestern and Echtermeyer (1982) suggest decompression of the muscle

compartments within 6 hours of the clinical onset of the compartment syndrome would likely to result in no late sequelae.

The dead and disintegrating muscle cells can release the muscle pigment myoglobin into the surrounding tissue fluid and this can then reach the blood circulation, especially after release of the raised intracompartmental pressure. This may cause the presence of myoglobin in the urine (myoglobinuria), this being an indication of extensive muscle death. Myoglobinuria may be expected to start within a few hours of the restoration of the muscle circulation by fasciotomy.

near cortex: The bony cortex near the operator and on the side of application of an implant. Usually a term used in relation to plating, interfragmentary screw fixation and tension band wiring. In respect to bending, the convex near cortex contributes little to stability of fixation. When, for example, in wave plate application, the distance between the plate and the near cortex is increased, the bone and the repair tissues gain better leverage.

neutralization: An implant (plate, external fixator, or nail) which functions by virtue of its stiffness. The stiffness is said to "neutralize" the effect of the functional load. The implant carries a major part of the functional load and thus diverts loads away from the fracture locus and may serve to protect a more vulnerable element of a fixation complex. An example is where a spiral fracture has been reduced and fixed

with interfragmentary screws, and then a plate is applied to protect the primary screw fixation from functional loads which could disrupt it. The use of such a protection, or "neutralization," plate will allow earlier function aftercare than had the screw fixation been left unsupported. It does not actually "neutralize," but does minimize, the effect of the forces (see protection).

non-steroidal inflammatory drugs: See **NSAIDS**.

nonunion (or non-union): (See also **union, pseudarthrosis, delayed union**) Nonunion is failure of bone healing. A fracture is judged to be ununited if the signs of nonunion are present when a sufficient time has elapsed since injury, during which the particular fracture would normally be expected to have healed by bony union. That period will vary according to age, fracture location and patho-anatomy.

The signs of nonunion include persisting pain and/or tenderness at the fracture sight, pain and/or mobility on stressing the fracture site, and inability progressively to resume function. Slight warmth may be detected if the fracture site is subcutaneous. Radiographs will be likely to show failure of re-establishment of bony continuity.

When a fracture has been fixed internally, loosening and/or breakage of the implant may indicate the instability of a nonunion. If a nonunion has resulted from a mechanical environment at the fracture locus that is not conducive to bone healing, despite good

fracture biology and osteogenic response, a hypertrophic nonunion ("elephant's foot") occurs—the solution to this is a mechanical one.

If a nonunion has resulted from impaired biological response at the fracture locus, an atrophic nonunion occurs—the solution to this is biological enhancement, usually with mechanical support.

NSAIDS: Non-steroidal inflammatory drugs. See **http://www.healthline.com/galecontent/nonsteroidal-anti-inflammatory-drugs-1**

open fracture: Fractures with an overlying, communicating wound of the integument, exposing the fracture site to contamination and the risk of infection. Open fractures are commonly graded according to the severity scale of Gustilo, Mendoza and Williams (*J Trauma,* 1984). This scale comprises grades 1, 2, 3A, 3B and 3C, from the least to the most severe soft tissue damage.

opposition (anatomical): The action of opposing one part to another; if the pulp of the thumb is placed in contact with the pulp of a finger, the movement, or action, of the thumb is that of opposition.

ORIF: A widely used abbreviation for open reduction and internal fixation (osteosynthesis).

osteoarthritis: This is a degenerative condition which affects diarthrodial (**synovial**) joints and is characterized by loss of articular cartilage, reactive subchondral bone sclerosis (sometimes with subchondral cysts) and the formation of peripheral bony outgrowths—osteophytes. The primary lesion is degeneration of the articular cartilage as a result of infection, trauma, overuse, congenital skeletal anomaly, or as part of the aging process.
Osteoarthritis may be primary, where there is no identifiable prior insult to the articular cartilage (usually associated with the aging process), or secondary, in which case the degeneration of the articular cartilage is initiated by congenital joint abnormality, injury, infection, deformity of the limb, joint instability, identifiable overuse, inflammatory joint disease, such as "burnt out" **rheumatoid arthritis,** etc.

osteoarthrosis: See **osteoarthritis.**

osteoblast: A cell that forms new bone.

osteoblastic: Producing bone.

osteoclast: Cell that destroys bone. Osteoclasts rest in the Howship lacunae (small spaces within the bone surface). They are typically found at the tips of the remodelling osteons, but also in all sites where bone is being removed by physiological processes.

osteolytic: Resorbing, destroying or removing bone.

osteomyelitis: An acute or chronic inflammatory condition affecting bone and its medullary cavity, usually the result of bacterial (occasionally viral) infection of bone. This may be a blood-borne infection (haematogenous osteomyelitis), usually in children or in the immunologically compromised, or follow an open fracture (post-traumatic osteomyelitis).
The acute form, if diagnosed early and treated vigorously, can heal with no residual effects. If the diagnosis is delayed then the infection and the consequent interference with the local bone blood supply can result in dead bone (which may separate to form one or more sequestra—see **sequestrum**) that remain infected in the long term because the defence mechanisms have no vascular access to it. The treatment of chronic osteomyelitis is surgical and includes wide excision of all dead and infected tissue, the identification of the responsible organism, and the delivery, both locally and systemically, of appropriate antibacterial agents.

osteon (osteone; cutter cone): This is a normal vascular structure concerned with bone remodelling, either as part of physiological bone turnover, or as part of the healing process after fracture. Anosteon comprises a vascular bud, at the tip of which is a cluster of osteoclasts. Behind the osteoclasts, the vessel is cuffed by osteoblasts. As the osteoclasts remove bone, they advance through the bone and the following cuff of osteoblasts lays down concentric cylinders of osteoid, which matures to form the rings of bone seen in the walls of the **Haversian systems** of bone. The osteon effectively drills a channel through existing bone, and then lines this channel with cylinders of new bone.

osteopaenia (osteopenia): An abnormal reduction in bone mass. This may be generalized, as in some bone diseases, or localized, as a response to inflammation, infection, disuse, etc. See **osteoporosis.**

osteoporosis: A reduction in bone mass. It is a natural aging process but may be pathological. It can result in pathological fracture (most fractures of the femoral neck in the elderly are due to osteoporosis plus minimal trauma). See **osteopaenia** and **pathological fracture.**

osteosynthesis: A term coined by Albin Lambotte (1907) to describe the "synthesis" (derived from the Greek *suntithenai* for putting together, or fusing) of a fractured bone by a surgical intervention using implanted material. It differs from "internal fixation" in that it also includes external fixation.

osteotomy: Controlled surgical division of a bone.

overbending (of plate): See **prebending.**

palmar: Pertaining to the palm of the hand, eg, the palmar fascia, the palmar aspect of the fingers.

pathological fracture: A fracture through bone which is abnormal as a result of a pathological process. It may be the result of the application of a force less than that which would be required to produce a fracture in a corresponding normal bone.

periosteal: Adjective derived from **periosteum.**

periosteum: Is the inelastic membrane bounding the exterior surface of a bone. The periosteum plays an active part in the blood supply to cortical bone, in fracture repair and in bone remodelling. It is continuous with the perichondrium—the membrane that bounds the periphery of the physis.

pilon: The distal end of the tibia, from the French for a stump, or a pestle. Fractures of the distal tibial metaphysic caused by axial load failure are called "pilon fractures."

pilot hole: If a fully threaded screw is to function as a lag screw, the screw is anchored near its tip, within a threaded hole in the far bone fragment. The original drill hole which is made prior to tapping of the thread in the bone is called the pilot hole. Within the bone fragment near head of the screw, the thread should not obtain purchase but should

glide (**gliding hole**). A pilot hole is also prepared when inserting a Schanz screw, or a Steinmann pin.

pin loosening: The pins of external fixator frames serve to stabilize the fragments of a fracture by linking the bone to the frame. Stability depends, among other things, upon the contact between pin and bone (pin-bone interface). Pin loosening occurs when bone surface resorption at the pin-bone interface takes place due to excessive cyclical loading of the bone. Stability is thereby reduced. However, pin loosening is less important in respect of loss of stability than in respect of its deleterious effect in promoting pin track infection.

plafond (French): Literally "ceiling" used to denote the horizontal portion of the distal tibial articular surface. See **pilon.**

plantar: Pertaining to the sole of the foot, ie, the surface of the foot which is "planted" on the ground. Examples are the plantar fascia, and the plantar surfaces of the toes. Plantar flexion is a movement at the ankle which moves the foot downward, or in a plantar direction.

plastic deformation: If an object is deformed within those limits which allows it to regain its original form, once the deforming force is removed, it is said to have undergone elastic deformation. If the force is increased above the upper level for elastic deformation, permanent deformity (known

in engineering terms as "set") is produced— this is plastic deformation. When the deforming force is removed, the object cannot return to its original form. Plastic deformation, without fracture, can occur in the shape of a young, growing bone following the application of a deforming force. The alteration in shape does not "rebound" to the original as the bone has been stressed beyond its elastic limit, but not to the point of breaking.

polytrauma: Multiple injuries to one or more body systems. An Injury Severity Score (ISS) of more than 16 is usually taken to indicate polytrauma.

posterior: The back of the body in the anatomical position is the posterior surface. If A is nearer to the back of the body in the anatomical position than B, then A is posterior to B. Equivalent to dorsal, except in the foot, where the dorsum is anterior in the anatomical position—see **dorsal.**

prebending of plate: Exactly contoured plates, when loaded using either the external compression device or the DCP principle, produce asymmetrical compression, ie, the **near cortex** is more compressed than the far cortex. Indeed, the latter may not be compressed at all and can be distracted in certain cases. To achieve stabilization against both torque and bending, compression at the far cortex is even more important than that of the near cortex. To provide uniform compression across the whole width of the

bone, including the far cortex, the plate is applied after contouring with an additional bend of the plate segment bridging the fracture. The bend is such that the midsection of the plate is slightly elevated from the surface of the reduced fracture, prior to fixation to the bone and the application of compression. Prebending is an important tool to increase stability in small and/or osteoporotic bones—see **osteopaenia**.

precise reduction: See **anatomical reduction.**

preload: The application of interfragmentary compression keeps the fragments together until a tensile force is applied, exceeding the compression (preload).

pronation: The movement of rotating the forearm so that the palm of the hand faces backward from the anatomical position. Pronation is also sometimes used to describe a movement of the foot into inclination away from the midline, otherwise called eversion; so that a pronated foot would bear more weight on its medial border than on its lateral border.

prophylactic: Preventive.

protection: While the term "neutralization" has often been used in plate and screw fixation, the term "protection" should replace it. In reality nothing is neutralized. In plate fixation the plate reduces the load placed upon the interfragmentary screw fixation. It therefore protects the screw fixation from overload—see **neutralization.**

proximal: Nearer to the centre of the body in the anatomical position. The opposite of **distal.** Thus, the elbow is proximal to the wrist. In certain instances, it means nearer the beginning than the end; for example, in the digestive system the stomach is proximal to the ileum, or in the urinary tract the kidney is proximal to the bladder.

pseudarthrosis: See also **delayed union, nonunion, union,** literally means "false joint." When a nonunion is mobile and allowed to persist for long periods, the ununited bone ends become sclerotic and the intervening soft tissues differentiate to form a crude sort of synovial articulation. The term is often loosely and incorrectly used to describe all nonunions. Occasionally, a pseudarthrosis (in the sense of a false articulation) may be deliberately created surgically, as for example, in excision arthroplasty of the hip (Girdlestone, Judet, Robert Jones), or excision of a segment of the distal ulnar shaft, in combination with fusion of the inferior radioulnar joint (Kapandji). Excision of the radial head is another example of surgical pseudarthrosis.

pure depression: An articular fracture in which there is depression alone of the articular surface without split—see **impacted fracture** and **pure split.**

pure split: An articular fracture in which there is a longitudinal metaphyseal and articular split, without any additional osteochondral lesion.

radial preload: To prevent external fixator pin loosening, the contact zone (interface) between the implant and bone can be preloaded, ie, a static compressive force is applied. Hitherto, preloading was achieved by applying a permanent bending moment to the pins, within their elastic range. Currently, the pins are designed with a thread and shank that automatically generate radial preload, ie, a tight, compressive fit produced by insertion of a pin slightly larger than the drill hole. The effect of radial preload is to minimize pin loosening and to seal the pin track so that a potential infection cannot reach the medullary cavity from outside. The amount of misfit between the hole diameter and the pin diameter should not exceed 0.05–0.1 mm. Such a precise geometric discrepancy can only reliably be ensured by using self cutting tips. See **preload.**

radiotherapy: Treatment of pathological conditions, usually malignant, with ionizing radiation. It has been recommended in low dosage to discourage heterotopic bone formation.

recurvatum: An angular deformity, usually of a long bone, in which the distal part is angulated anteriorly, so that the apex of the angle is posterior.

reduction: The realignment of a displaced fracture or a dislocated joint.

reflex sympathetic dystrophy (RSD): One of the names given to algodystrophy—the chronic regional pain syndromes. Usually follows an injury, not always a fracture. Characterised by chronic pain that fails to resolve within the time commensurate with the injury, swelling of the part, joint stiffness, alteration in skin colour, texture and/or temperature and associated with demineralization of the local bone, especially in the bone just beneath the articular cartilage (subchondral bone). See **complex regional pain syndrome.**

refracture: A fracture occurring at a former fracture site, after the bone has solidly bridged, at a load level otherwise tolerated by normal bone. The resulting fracture line may coincide with the original fracture line, or it may be located remote from the original fracture, but within the area of bone that has undergone changes as a result of the fracture and its treatment.

relative stability: see **stability of fixation.** remodelling (of bone): The process of transformation of external bone shape (external remodelling), or of internal bone structure (internal remodelling, or remodelling of the **Haversian system**).

resorption (of bone): The process of bone removal includes the dissolution of mineral and matrix and their uptake into the cell (phagocytosis). The cells responsible for this process are **osteoclasts.**

rheumatoid arthritis: a crippling, aseptic, synovial inflammatory disease, usually involving many joints (polyarthritis). Results in an intense synovitis that eventually erodes the articular cartilage and the underlying subchondral (beneath the cartilage) bone.

rigid fixation: A fixation of a fracture which allows little or no deformation under load—see **stability of fixation.**

rigid implants: In general implants are considered to be rigid when they are made of metals. The implant geometry is more important than the physical stiffness of the material. Most implants made of metal are much more flexible (less rigid) than the corresponding bone.

rigidity: This term is often used synonymously with stiffness. Some (Timoshenko, 1941) believe that its use should be confined to considerations of shear (eg, at the interface of plate and bone).

rotator cuff: A musculotendinous "hood," or cuff comprising the muscle bellies and the aponeurotic tendons of the supraspinatus, infraspinatus and subscapularis muscles, passing from their origins from the scapula to their insertions into the tuberosities of the upper humerus. This sheet of tendinous tissue lies between the head of the humerus and the undersurface of the acromio-clavicular arch—in the sub-acromial interval. These muscles play an important role in controlled shoulder movement and in stabilising the shoulder. A rupture of the rotator cuff allows the head of the humerus to migrate upward and come into abnormal articulation with the undersurface of the acromioclavicular arch, resulting in later degenerative change.

sagittal: Literally, it means pertaining to an arrow (*sagitta* is Latin word for arrow). Bisection of the body in the sagittal plane would divide it into left and right halves, so-called because an arrow fired into the body would normally strike from the front and would pass in a sagittal direction.

scarf test: A test for acromioclavicular dysfunction, and the patient experiences pain in the acromioclavicular joint when bringing the forward flexed arm across the front of their body, as if to "toss a scarf" over the opposite shoulder (this movement is called horizontal adduction).

scoliosis: A spinal deformity in which there is one, or more, curvature in the coronal plane, which may be postural or structural. The latter is often associated with rotational deformity. See also **kyphosis.**

second look: Surgical inspection of a wound or injury zone, 24 to 72 hours after the initial management of a fracture or wound.

segmental: If the shaft of a bone is broken at two levels, leaving a separate shaft segment between the two fracture sites, it is called a "segmental" fracture complex.

sequestrum: A piece of dead bone lying alongside, but separated from, the osseous bed whence it came. It is formed when a section of bone is deprived of its blood supply and the natural processes create a cleavage between the dead and the living bone. A sequestrum may be aseptic (sterile), as for example beneath a plate when there has been massive periosteal stripping and then a plate with a high contact "footprint" applied, killing the underlying bone. This is especially seen if a plate has been applied to the cortex at the same time as a reamed intramedullary nail has been inserted. Infected sequestra are formed in chronic osteomyelitis—see **osteomyelitis.**

shear: A shearing force is one which tends to cause one segment of a body to slide upon another, as opposed to tensile forces, which tend to elongate, or shorten, a body.

shock: A state of reduced tissue perfusion, usually due to a fall in blood pressure secondary to hypovolaemia, overwhelming sepsis (gram negative shock, or "red" shock), or allergic anaphylaxis.

shoulder examination: See **http://www. usask.ca/cme/articles/fmse/index.php**

simple (single) fracture: A disruption of bone with only two main fragments. Formerly used to denote a fracture that was not "compound" (or open).

splinting: Reducing the mobility at a fracture locus by coupling a stiff body to the main bone fragments. The splint may be external (plaster, external fixators) or internal (plate, intramedullary nail).

split depression: A combination of split and depression in an articular fracture—see **pure split** and **pure depression.**

spondylolisthesis: The forward slip of one vertebral body on the one below it. This may be due to congenital elongation of the pars interarticularis of the vertebra, **spondylolysis**, degenerative joint disease affecting the intervertebral facet joints, and rarely an acute fracture of the pars interarticularis.

spondylolysis: The presence of a loss of continuity of the pars interarticularis of a vertebral body. This can lead to instability and forward slip of one vertebral body on the one below it—**spondylolisthesis.**

spondylosis: Degenerative change at one or more levels in the spinal column: degenerative intervertebral disc disease.

spontaneous fracture: One that occurs without adequate trauma, usually in abnormal bone—see **pathological fracture.**

spontaneous healing: The healing pattern of a fracture without treatment. Solid healing is observed in most cases, but malunion frequently results. This is how animal fractures normally heal in the wild.

stability of fixation: This is characterized by the degree of residual motion at the fracture site after fixation (ie, very little or no displacement between the fragments of the fracture). In technical terms, stability describes the tendency to revert to a condition of low energy, but this strict definition is not adhered to in lingua franca of fracture surgery.

Stability, absolute: The compressed surfaces of the fracture do not displace under applied functional load. The definition of absolute stability applies only to a given time and at a given site: some areas of a fracture may displace in relation to each other whilst other areas of the same fracture locus may not; different areas may also exhibit different displacements at different times. Practically, the only method of achieving absolute stability consists in the application of interfragmentary compression. The compression results in stability by preloading the fracture interface and by producing friction (Perren, 1972).

Stability, relative: An internal fixation construct that allows small amounts of motion in proportion to the load applied. This is the case with a fixation that depends exclusively on the stiffness of the implant

(such as a nail, or plate, bridging a multifragmentary fracture segment). The residual deformation or displacement is inversely proportional to the stiffness of the implant. Such motion is always present, but usually harmless, in nail fixation. According to the philosophy of the AO ASIF group, plate fixation is more reliable if motion can be prevented, but never at the expense of the biology of the fracture locus—see **biological fixation.**

stable fixation: A fixation which keeps the fragments of a fracture in motionless adaptation during the application of controlled physiological forces. While a mobile fracture produces pain with any attempt to move the limb, stable fixation allows early painless functional rehabilitation. Thus, stable fixation minimizes irritation, which could eventually lead to fracture disease—see **stability of fixation.**

stiffness: The resistance of a structure to deformation. Under a given load, the higher the stiffness of an implant then the smaller its deformation, the smaller the displacement of the fracture fragments and the lower the strain generated in the repair tissue. Excessive tissue strain can interfere with healing. The stiffness of a structure is expressed as its Young's modulus of elasticity.

Stiffness and geometrical properties: The thickness of a structure affects deformability by its third power. Changes in geometry are, therefore, much more critical than are

changes in material properties, a fact which is often overlooked by non-engineers. Thus, if flexible fixation is a goal, it can be achieved more effectively and in a more controlled manner by small changes of implant dimension than by using a "less rigid" material.

strain: Relative deformation of a material, for example, repair tissue. Motion at the fracture site in itself is not the important feature, but the resulting relative deformation, which is called strain ($\delta L/L$), of the healing tissues. As strain is a ratio (displacement of fragments divided by width of fracture gap), very high levels of strain may be present within small fracture gaps even under conditions where the displacement may not be perceptible.

strain induction: Tissue deformation, among other things, may result in induction of callus. This would be an example of a mechanically induced biological reaction. For those reactions triggered by strain, such as callus formation and bone surface resorption, the concept of a lower limit of strain, the minimum strain, is to be considered.

strain tolerance: This determines the tolerance of the repair tissues to mechanical conditions. No tissue can function normally when an increase in length (ie, strain) causes the tissue to disrupt. This the critical strain level. Above such a critical level, tissues strain will disrupt the tissue once formed, or will prevent its formation.

strain theory (Perren): With a small fracture gap, any movement will result in a relatively large change in length (ie, high strain). If this exceeds the strain tolerance of the tissue, healing will not take place. If a larger fracture gap is subject to the same movement, the relative change in length will be smaller (ie, less strain) and, if the critical strain level is not exceeded, there will be normal tissue function and indirect healing by **callus.**

strength: The ability to withstand load without structural failure. The strength of a material can be expressed as ultimate tensile strength, as bending strength or as torsional strength. The local criterion for failure of bone, or of implants, is measured in units of force per unit area: stress, or (equivalent) deformation per unit length (strain), or elongation at rupture.

stress protection: This term, initially used to describe bone reaction to reduced functional load (Allgöwer et al, 1969) is used today mainly to express the negative aspects of any stress relief of bone. The basic assumption is that bone, deprived of its necessary functional stimulation by reducing its mechanical load, becomes less dense and so less strong (Wolff's law). Stress protection is often used synonymously with stress shielding, that is in a purely mechanical sense. It is often used to characterize bone loss, implying a negative connotation to stress shielding. With regard to the internal fixation of cortical bone, stress protection

seems to play no important role, compared with vascular considerations—**see stress shielding.**

The early bone loss seen deep to a plate, which has in the past been attributed to stress protection, can better be explained on the basis of a denial of blood supply to the underlying cortex, due to the pressure of the "footprint" of the plate. The resultant necrotic bone is then remodelled by osteons, which originate from the well vascularized, adjacent cortex. This remodelling process is associated with a temporary osteoporosis. Investigations of late bone loss under clinical conditions of internal fixation in the human, using quantitative computed tomography, show very little residual bone loss at the time of implant removal (Cordey et al, 1985). In summary, bone may react to unloading but this plays a minor role in internal fixation of cortical bone fractures.

stress riser: In any body subject to deformation, stress will be generated within its material. If any part of the body is weaker than the rest, there will be a concentration of stress (high mean stress) at this place. If an implant is notched by inappropriate handling, the area of damage will act as a stress riser and produce the risk of fatigue failure with cyclical loading. If a hole is drilled in a bone and then left empty, this too will result in high mean stress and the risk of fracture. With the exception of the LCD-CP, with its even strength, most plate holes represent weaker points on the plate than the solid sections between the plate holes: in

a fixation with such a plate, where a screw hole has been left unfilled in the fracture zone, the empty hole acts as a stress riser and also produces the risk of fatigue failure, or bending under high functional load.

stress shielding: When internal fixation relies upon screws and plates, the stability of the construct is achieved mainly by the interfragmentary compression exerted by the lag screws. Lag screw fixation alone is very stable, but generally provides little security under functional load. A plate providing protection (or neutralization) is therefore often added. The function of such a plate is to reduce the levels of peak load passing through the lag screw fixation. Protection is provided by virtue of the stiffness of the plate. The plate shields the fracture's primary fixation with screws—see **neutralization** and **protection.**

subchondral: Means beneath the cartilage.

Sudeck's atrophy: One of the names given to algodystrophy, **complex regional pain syndrome,** or **reflex sympathetic dystrophy.**

superior: Literally above, or better than. In the anatomical position, if A is higher than, or above, B, then A is superior to B. The opposite is inferior.

supination: The movement of rotating the forearm that causes the palm of the hand to face forward, that is restoring the hand to the

anatomical position. Supination is also sometimes used to describe a movement of the foot into inclination toward the midline, otherwise called inversion; a supinated foot would bear more weight on its lateral border than on its medial border

synovectomy: Excision of the synovial membrane. **Synovial joint** (**diarthrodial joint**): the most common form of joint in the body, where two bone ends, each covered with hyaline cartilage, articulate, the one on the other. They are bound together by a joint capsule and ligaments. The interior of the joint, other than the cartilage surfaces, is lined by **synovial membrane**, which secretes synovial fluid as a lubricant and a nutrient transport fluid.

synovial membrane: The membrane lining the interior of a **synovial (diarthrodial) joint,** wherever the interior surface does not bear articular cartilage.

systemic: Refers to any route for drug, or fluid, administration, other than via the gastrointestinal tract, and usually by injection.

tension band: An implant (wire or plate) functioning according to the tension band principle: when the bone undergoes bending load, the implant, attached to the bone's convex surface, resists the tensile force. The bone, especially the far cortex, is then dynamically compressed. The plate is able to resist very large amounts of tensile force,

while the bone best resists compressive load: this bone-implant composite therefore is ideally suited to resist the bending force.

threaded hole: Discussed in conjunction with **pilot hole.**

tibial intercondylar eminence: The area of the proximal tibia lying between the medial and lateral tibial plateaux, which is non-articular and bears the attachments of the horns of the two menisci, and of the tibial ends of the anterior and posterior cruciate ligaments to the anterior and posterior tibial spines.

tibial spine: See **tibial intercondylar eminence.**

torus: A geometrical body in the shape of a solid ring that in cross-section is circular, or elliptical, such as an inflated tyre inner tube. It is a term used in architecture to describe the circumferential bulge seen at the top and bottom of classical columns. It has been applied to the "wrinkle" or "buckle" appearance seen in the compression cortex of angular fractures of young children's bones (torus fracture).

toxins: Poisonous chemicals. Some pathogenic organisms release powerful toxins when they multiply and some when they die.

trabecula (pl. trabeculae): A solid bony strut of cancellous bone. Literally, a small beam or bar.

tracheostomy: Surgical opening into the trachea (windpipe), usually to assist ventilatory support.

tract: Literally, a treatise or document (often religious), an anthem, an extent of territory, or an anatomical structure comprising mixed tissues organized to serve a specific physiological function (spino-thalamic tract, urinary tract, gastrointestinal tract, etc). It is commonly misused to describe the path created surgically through tissues by the insertion of an external fixator pin. In that context, the word "track" should be used (in the sense of its meaning the mark, or trail, left by the passage of anything—Oxford English Dictionary).

trans-cortex: See **far cortex.**

transverse: Meaning across. Transverse bisection of the body in the anatomical position would divide it into upper and lower halves. Not the same as horizontal, which means parallel with the horizon. Thus if the body were lying flat on its back (supine), horizontal would be the same as the **coronal plane,** but if the body were standing, in the anatomical position, horizontal would be in the transverse plane. In other words, horizontal is always related to the horizon, whereas the anatomical planes (coronal, frontal, sagittal, transverse) always relate to the anatomical position.

union: Strictly speaking, union means "as one"—as in marital union, a workers' union,

even national groups, eg, the United States. Equally strictly, if a fracture is fixed so that the bone functions as a single unit, then it has been surgically "united" (osteosynthesis): the bone is not, however, healed. Bone healing is a process initiated by fracture and continuing until the bone is restored to its final state by remodelling, which may take years. We speak loosely of a fracture's being united, but this is not a discrete event. What we are saying is that a healing fracture has reached the point in the process of union when the experienced surgeon estimates that it can withstand normal functional loads for that patient. Union is, therefore, a judgment, usually based upon a synthesis of temporal, clinical and imaging information. This calls into question the validity of "time to union," which is reported in so much of the surgical literature as a parameter for the judgment of the comparative efficacy of different treatments.

valgus: Deviation away from the midline in the anatomical position. Thus, genu valgum is a deformity at the knee where the lower leg is angled away from the midline (knock knee). By convention any deformity, or deviation, is described in terms of the movement of the distal part.

varus: Deviation toward the midline in the anatomical position. Thus, genu varum is a deformity at the knee where the lower leg is angled toward the midline (bow leg). By convention any deformity, or deviation, is described in terms of the movement of the distal part.

vascularity: That property of a tissue which reflects the extent to which it has, or does not have, a blood supply.

A tissue is said to be vascularised if its intrinsic network of blood vessels is connected to the main circulatory system. Blood vessels may be shut off temporarily from the circulatory system. If the connection to the main circulation is permanently interrupted, or if the vessels present are not functioning, eg, obliterated by thrombosis, the tissue is said to be avascular, or devascularized. We consider a tissue to be nonvascular if there are normally no functioning vessels, as in hyaline cartilage.

vertical: Upright. Perpendicular to horizontal. Derives from vertex, meaning the top, as in the vertex of the skull.

wave plate: If the central section of a plate is contoured to stand off the near cortex over a distance of several holes, it leaves a gap between the plate and the bone, which (a) preserves the biology of the underlying bone, (b) provides a space for the insertion of a bone graft and (c) increases the stability because of the distance of the "waved" portion of the implant from the neutral axis of the shaft. Such plating is useful in nonunion treatment.

wedge fracture: Fracture complex of the shaft of a long bone, with a third fragment, in which, after reduction, there is some direct contact between the two main shaft fragments—see **butterfly fragment.** Also

used to describe a compression fracture of a vertebral body, where the body has been crushed anteriorly and made wedge-shaped.

working length: The distance between the two points of fixation (on either side of the fracture) between an implant, usually an intramedullary nail, and the bone.

xenograft: A graft of tissue from an individual of one species (donor) to a recipient (host) of another species.

zone of injury: The entire volume of bone and soft tissue damaged by energy transfer during trauma.